

THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 22

APRIL, 1937

No. 4

THE GRANITE PEGMATITES OF SOUTHERN NORWAY

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INTRODUCTION

The rare minerals of the granite pegmatites of southern Norway have been studied especially by Brøgger (7, 8), Schetelig (8, 12), and Vogt (8). However, recently many new pegmatites have been opened for feldspar production, and the use of x -ray spectrographic methods has made it possible to study the composition of a larger number of their minerals.

The results given in this paper are based on field observations of the granite pegmatites of southern Norway made during the summers 1931–36, and laboratory investigations of the materials collected. Most of the minerals collected were only small fragments of crystals, or irregularly formed nodules, and many of them could not have been identified without the use of special methods. To this end x -ray spectral analyses were used. The x -ray spectrograms give positive identification of most of the rare minerals and, since an amount of 2–3 mg. of the mineral powder suffices, very small mineral particles can be studied and classified. They also give a good survey of the variation of the chemical components in each mineral specimen. For identification purposes, also Debye-Scherrer diagrams were used to some extent. A total number of about 400 x -ray spectrograms from Norwegian granite pegmatites have been made. The classification of these pegmatites is based chiefly on a study of several hundreds different pegmatites in Sørlandet (Iveland county and the coastal region) and Østfold (Region E. of the Oslofjord). Mineralogical descriptions of the material used, as well as a description of the laboratory methods, have been published in previous papers (4, 5, 6).

ORIGIN OF THE PEGMATITES

It is generally accepted that granite pegmatites carrying rare minerals represent residual granite liquors enriched in volatile components and characteristic rare elements. According to Goldschmidt (9), the enrichment of rare elements is caused by the fact that the ionic radii of these elements are different from those of the common rock-forming elements of the granite. In the Norwegian granite pegmatites the following rare

elements are characteristically present: Ti, Nb, Ta, W, and Be. However, the amounts of these rare elements vary within wide limits in the different pegmatites. In some large pegmatite dikes no minerals of rare elements have been encountered, while in others they occur abundantly. At the same time, pegmatites differing in their content of rare minerals may be very similar in their content of the principal minerals. It seems impossible, therefore, to find any relationship between the main composition of the pegmatites and the amount of rare minerals.

Investigations of Norwegian granite pegmatites carried on during the last six years, especially in Iveland, have shown that, generally speaking, pegmatites containing insignificant amounts of rare minerals form rather regular, dike-shaped bodies, while irregular or lens-shaped pegmatites almost always contain rare minerals in considerable quantities.

Coarse granite pegmatites must have been subjected to slow cooling, and since they usually form relatively small bodies or dikes, the neighboring rocks must have maintained a temperature near that of the crystallization interval of the pegmatites for a long time. It is assumed, therefore, that such pegmatites were formed at a certain depth where the pressure was large enough to keep the volatiles in solution, and where the temperature was approximately that of the crystallization of the pegmatites.

If a granite pegmatite magma has been intruded into rocks with a temperature above the temperature of crystallization of the pegmatite no crystallization could take place, and this pegmatite magma should remain in a liquid condition until the temperature of the surrounding rocks was low enough to permit crystallization. Such a lowering of the temperature of the native rock may be effected by denudation.

As previously pointed out by Andersen (1) and Barth (2, 3) the granite pegmatites often occur as lens-shaped or irregular masses without any traceable connection with other granite bodies, and Andersen, therefore, assumes that the pegmatite magma filling these spaces was intruded along small cracks or channels in the surrounding rock. It is a common phenomenon that the surrounding rock has developed a schistosity parallel to the pegmatite bodies. Since microcline and quartz of the pegmatites usually exhibit no sign of pressure, the deformation of the adjacent rock must have taken place before the crystallization of these minerals, i.e. while most of the pegmatite magma still was in a liquid condition. It seems unlikely that this pressure was caused by the intrusion of the pegmatite magma through narrow cracks or channels in the surrounding rock. It seems more probable that the pressure was caused by stress forces subsequent to the intrusion, but before complete crystallization of the pegmatite magma. This view is supported by the fact

that many granite pegmatites contain strongly deformed crystals of the early mineral phases: beryl, tourmaline, euxenite, columbite, and biotite (incidentally the mechanical deformation of these minerals is a further indication of their magmatic origin); whereas the mineral phases of the principal stage of crystallization: feldspar, quartz, etc., seldom show any trace of deformation.

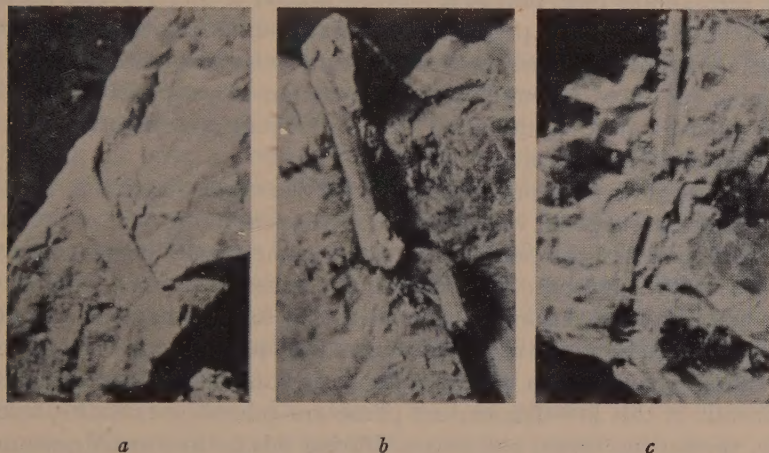


FIG. 1. Mechanically deformed crystals in microcline from granite pegmatite, Torvelona in Iveland ($1\frac{1}{2}\times$); *a* and *b* euxenites, *c* beryl. (For photographic purposes the samples have been whitened with ammonium chloride.)

Some intrusive granite pegmatites in Iveland send forth into the amphibolite small subparallel veins and apophysae that can be traced over great distances. Goldschmidt (9) previously has pointed to the fact that potash extracted from the pegmatite often transforms hornblende into biotite on the boarder of the amphibolite. The small pegmatite veins are richer in plagioclase, therefore, and also richer in quartz than the larger pegmatites. By spectroscopic analyses of the amphibolite Goldschmidt (10) has shown that scandium does not belong to the pegmatite magma but has been extracted from the surrounding amphibolite. It is a characteristic feature that the thortveitite-bearing pegmatites always form small pocket-shaped bodies in the amphibolite.

The relative amounts of the principal mineral phases of the pegmatites vary within wide limits, and according to Barth (3) the granite pegmatites in northern Iveland can be divided into two types: type 1 with 20% quartz and 80% microcline; and type 2 with 50% quartz, 25% microcline and 25% plagioclase.

The contention of the present writer is that the Norwegian granite pegmatites carrying rare elements have been formed as follows: after the injection of the younger pre-Cambrian granites, the residual granite magma, enriched in volatiles and rare elements, was intruded along cracks in the surrounding rocks. The temperature was however still high enough for the magma to remain in a liquid condition in these rocks for a long time. Through orogenic movements the magma was kneaded into the surrounding rock, part of it forming smaller or larger bodies without connection with other pegmatite material. During this time the initial crystallization stage was reached, the early mineral phases thereby becoming subjected to mechanical deformation as previously described, the adjacent rock at the same time developing a schistosity parallel to the pegmatite bodies.

Evidence of a filter press action during the crystallization is afforded by the numerous small veins and apophysae containing none of the early mineral phases of the pegmatite magma. Some granite pegmatites were subsequently influenced by solutions and gases following cracks in the already congealed magmatic pegmatite, thus forming deposits of hydrothermal-pneumatolytic origin (cleavelandite, quartz etc.), which are not of course in equilibrium with the magmatic minerals. Characteristic rare minerals of this low-temperature phase are columbite-tantalite, microcline, spessartite, topaz, and zircon. During this hydrothermal-pneumatolytic stage the magmatic minerals near the pathways of the gases and solutions were partly or wholly replaced by cleavelandite and quartz. Vestiges of this replacement can still be seen: patchy remainders of partly dissolved magmatic minerals, especially microcline, encompassed by cleavelandite or quartz, monazite and gadolinite imbedded in cleavelandite, beryl enclosing fergusonite, etc. However, cleavelandite pegmatites are relatively rare in Norway and occur only as small, distinctly younger dikes and veins in the magmatic pegmatites.

THE ACCESSORY ELEMENTS

Characteristic of the Norwegian granite pegmatites is the absence of minerals containing the elements lithium and tin. According to their ionic radii the characteristic accessory elements of the granite pegmatites may be divided into the following groups:

Group 1, the rare earth elements (yttrium, lanthanum and the lanthanides), Th, and U.

Group 2, Zr, and Hf.

Group 3, Ti, Nb, Ta, and W.

Group 4, Be.

These elements were present in small amounts in the original granitic

magma but were unable to form part of any of the principal mineral phases. They accumulated, therefore, in the residual liquid and crystallized eventually in individual minerals.

Group 1. The rare earths are chemically so closely related that they cannot be separated easily by ordinary chemical methods. However, through fractional crystallization during the congealing of the pegmatites a certain separation was effected, and thus, as first shown by Goldschmidt and Thomassen (11), it becomes possible to distinguish between three chief types of associations of rare earths:

(A) Selective associations of the Ce-elements, the Ce-group.

(B) Complete associations of the rare earth elements.

(C) Selective associations of the Y-elements, the Y-group.

In most of the minerals containing an appreciable amount of rare earth elements either association (A) or (C) is present, while association (B) is common in minerals with rare earths as minor constituents. Minerals of the A-association (the Ce-group) are monazite and orthite. The C-association, or the minerals with the Y-elements as chief chemical components are: xenotime; compounds with Ti, Nb, Ta, and W: fergusonite, euxenite, betafite, samarskite, and yttrantalite; silicates: thalenite, gadolinite, hellandite, and yttritanite.

In all these minerals Th and U may be present in considerable amounts. (When still larger amounts are present uraninite and thorite are formed.) As minor constituents the rare earth elements occur in apatite, thorite, uraninite, microlite, alvite, and spessartite.

Group 2. The elements Zr and Hf. X-ray spectrograms of Norwegian niobate and tantalate minerals show that the amounts of Zr in these minerals are always lower than 0.1%. Amounts of Zr in these minerals attaining 1% and even more, as given in some older analyses, are probably due to small inclusions of alvite. By far the greatest portion of Zr and Hf present in Norwegian granite pegmatites unites with SiO_2 forming zircon and alvite. Small amounts of Zr and Hf are also present in thortveitite, as previously pointed out by Goldschmidt (11).

Group 3. The elements Ti, Nb, Ta, and W. These elements of similar ionic radii can, at least partially, substitute for each other in a series of minerals. Especially closely related are Nb and Ta which are difficult to separate by ordinary chemical methods. The relative concentration of these elements does not seem to vary much in the various magmatic pegmatites, it probably is about 1 at. Ta:4-5 at. Nb.

In the Norwegian granite pegmatites Nb and Ta have reacted with the Y-elements, Fe, Mn, and Ca, with formation of the following minerals: fergusonite, euxenite, betafite, columbite, samarskite, yttrantalite, microlite, and tantalite. In all these minerals Ti and W may

be present in considerable amounts. In euxenite the atomic proportion $\text{Nb} + \text{Ta} : \text{Ti}$ varies from 1 to $\frac{1}{3}$. If Ti is present in the magma in relatively larger amounts than that corresponding to the euxenite formula, the excess of this element will enter into ilmenite, or under special conditions into titanite or ilmenorutile. In columbite from Iveland the content of WO_3 may attain 13%.

Group 4. Beryllium. This element is present in the Norwegian granite pegmatites in the minerals beryl, chrysoberyl and gadolinite. Of hydrothermal-pneumatolytic origin is phenakite which is known from two pegmatite dikes near Kragerø.

THE SEQUENCE OF CRYSTALLIZATION

In all magmatic granite pegmatites a distinct sequence of crystallization has been observed. The crystallization of the rare minerals always belong to an early stage. Among the principal minerals we find that the crystallization of biotite began very early and continued over a long period of time. The accessory minerals are therefore usually later than the inner parts, but older than the outer parts of the biotite crystals. Flakes of biotite have therefore often caught rare minerals and hemmed them in during the continued growth of the mica. The wedge-shaped spaces between two plates of biotite are, therefore, preferred loci for rare minerals. In some pegmatites rich in ilmenite large plate-shaped masses of ilmenite may enmesh the rare minerals in the same way as the biotite.

A regular sequence of crystallization is always observed.

- (1) The phosphates of the rare earth elements (monazite and xenotime) always belong to an early stage in the crystallization of the pegmatite.
- (2) The crystallization of the niobates and tantalates of the Y-elements proceeded in order of decreasing amounts of these elements. Thus the Y-rich fergusonite always comes before euxenite and betafite, which contain smaller amounts of yttria.
- (3) The niobates and tantalates of iron and manganese (columbite-tantalite) have always crystallized later than the niobates and tantalates of the Y-elements.
- (4) The accessory silicate minerals, thalenite, gadolinite, hellandite, and beryl are always later than the phosphates and the niobate and tantalate minerals.
- (5) The zirconium minerals, zircon and alvite, belong to the earliest crystallizations of the magma.

TABLE 1. THE GENERAL SEQUENCE OF CRYSTALLIZATION IN NORWEGIAN
MAGMATIC GRANITE PEGMATITES

Zirconium minerals.....	—
Phosphates of the rare earth elements.....	—
Niobates and tantalates of the rare earth elements.....	—
Niobates and tantalates of iron and man- ganese.....	—
The silicates of the rare earth elements.....	—
Biotite.....	—
Muscovite.....	—
Ilmenite.....	—
Magnetite.....	—
Beryl.....	—
Plagioclase.....	—
Microcline.....	—
Quartz.....	—

THE CLASSIFICATION OF THE NORWEGIAN GRANITE PEGMATITES

The granite pegmatites may be divided into the following genetic groups: (A) the magmatic pegmatites; and (B) the hydrothermal-pneumatolytic pegmatites.

A. THE MAGMATIC PEGMATITES

The magmatic granite pegmatites exhibit a series of different mineral parageneses which must be due to a differentiation of the rare elements in the magma before the intrusion of the pegmatites. In most of the pegmatites phosphorus has reacted with the rare elements forming monazite or, more infrequently, xenotime. Monazite is encountered in almost all pegmatites carrying rare earths, and it seems to be a stable mineral in nearly all mineral parageneses of the magmatic pegmatites. In some Ca-rich granite pegmatites apatite also occurs frequently.

The most characteristic rare minerals of the magmatic pegmatites are compounds of the rare earth elements with Nb and Ta, the different mineral parageneses in this case being caused by differences in the concentration of these elements in the pegmatite magma. The rare earth elements combine with phosphorus, Nb, Ta, Ti, and with silica. Usually the Y-elements will form various niobates and tantalates, however, in Ca-rich pegmatites, Ca-bearing niobates and tantalates, such as betafite, will form. It is expedient therefore to divide the magmatic pegmatites into two groups: (1) pegmatites poor in Ca, and (2) pegmatites rich in Ca.

1. *Pegmatites poor in calcium.*

The paragenesis of xenotime+columbite shows that the Y-elements under the given conditions have a greater affinity for phosphorus than for niobium and tantalum. On the other hand, columbite has never been found together with silicates of the Y-elements. The Y-silicates can only form, therefore, after the removal of niobium and tantalum from the magma through reaction with yttrium. Thus the mineral parageneses of the pegmatites are chiefly controlled by the ratio of the concentration between the Y-elements and Nb+Ta (in which may enter certain amounts of Ti and W). The atomic proportions of the common niobates and tantalates of the Y-elements are as follows:

Y-elements: Nb+Ta max. 1:1 fergusonite.

Y-elements: Nb+Ta max. 0.5:1 euxenite, yttrotantalite.

Y-elements: Nb+Ta max. 0.3:1 samarskite, betafite.

If the number of atoms of the Y-elements present in the magma (not counting the amounts combined with phosphorus as xenotime) be called *Y* and the number of Nb (+Ta, Ti, W) be called *M*, the variations in the proportions of these quantities will give rise to different mineral parageneses.

$Y:M > 1$. The excess *Y* will form the Y-silicates thalenite or gadolinite.

$Y:M = 1-0.5$. The total amount of *Y* will react with *M* and the orthoniobate fergusonite will be the first to form.

$Y:M = 0.5-0.3$. The amount of *Y* is not sufficient to form orthoniobates. The next niobates and tantalates to form are the meta-compounds and pyro-compounds, euxenite, yttrotantalite and samarskite.

$Y:M < 0.3$. The excess Nb and Ta will react with Fe and Mn forming columbites.

The elements Nb, Ta, Ti, and W are able to replace each other only to a certain extent in the various minerals. The relative concentration of these elements is, therefore, another factor governing the nature of the minerals to form. The atomic ratio between Nb and Ta seems to be fairly constant for the various magmatic pegmatites and is, therefore, of but small importance. The proportion Nb+Ta:Ti is subject to great variations and will, therefore, give rise to different mineral parageneses. The pegmatites may thus be divided into 3 groups:

- (a) The ratio Nb+Ta:Ti is too high for the formation of euxenite minerals. In these pegmatites Nb and Ta will react with the rare earth elements forming samarskite and yttrotantalite.
- (b) The ratio Nb+Ta:Ti corresponds to that of the euxenite minerals. In these pegmatites euxenite will be the characteristic mineral, but there will be no excess of Ti to form other Ti minerals.

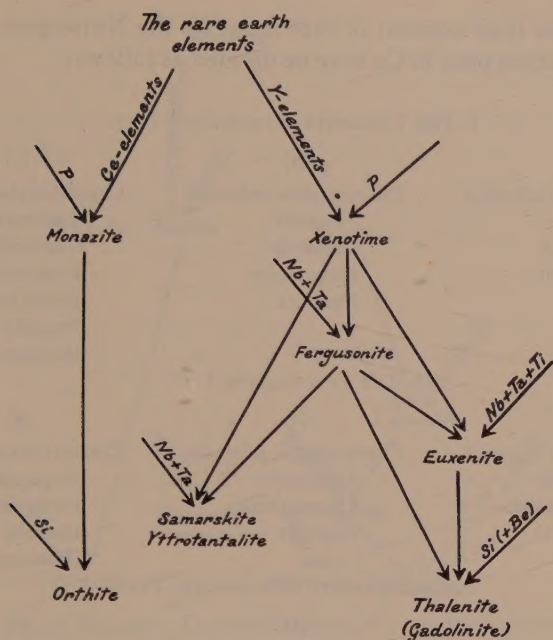


FIG. 2. Sequence of crystallization of the rare earth element-bearing minerals in the Ca-poor magmatic pegmatites.

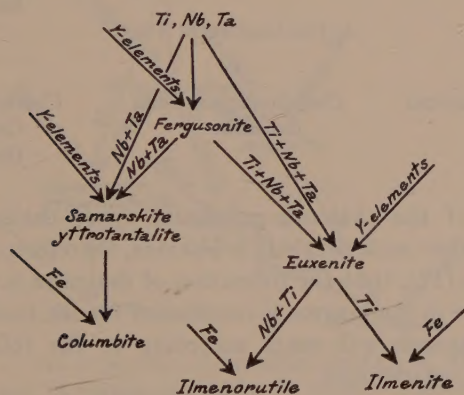


FIG. 3. Sequence of crystallization of the Ti, Nb, and Ta bearing minerals in the Ca-poor magmatic pegmatites.

- (c) The ratio $Nb+Ta:Ti$ is lower than in the euxenites. These pegmatites will have an excess of Ti, which will cause the formation of ilmenite or ilmenorutile.

According to their content of rare minerals the Norwegian magmatic granite pegmatites poor in Ca may be divided as follows:

1. THE THALENITE—GADOLINITE TYPE

(a)	(b)	(c)
Characteristic minerals	Characteristic minerals	Characteristic minerals
<i>Thalenite</i>	<i>Thalenite</i>	<i>Thalenite</i>
<i>Gadolinite</i>	<i>Gadolinite</i>	<i>Gadolinite</i>
Fergusonite	Fergusonite	Fergusonite
	Euxenite	Euxenite
		Ilmenite
		Ilmenorutile

2. THE FERGUSONITE TYPE

(a)	(b)	(c)
Characteristic minerals	Characteristic minerals	Characteristic minerals
<i>Fergusonite</i>	<i>Fergusonite</i>	<i>Fergusonite</i>
Yttrotantalite	Yttrotantalite	Euxenite
Samarskite	Euxenite	Ilmenite
		Ilmenorutile

3. THE EUXENITE (SAMARSKITE) TYPE

(a)	(b)	(c)
Characteristic minerals	Characteristic mineral	Characteristic minerals
<i>Samarskite</i>	<i>Euxenite</i>	<i>Euxenite</i>
Yttrotantalite		Ilmenite
		Ilmenorutile

4. THE COLUMBITE TYPE

(a)	(b)	(c)
Characteristic minerals	Characteristic mineral	Characteristic minerals
<i>Columbite</i>	<i>Columbite</i>	<i>Columbite</i>
Samarskite		Ilmenite

In pegmatites of the thalenite-gadolinite type, thalenite has never been found together with beryl. It is obvious, therefore, as first pointed out by Schetelig (12), that the formation of thalenite is possible only if the amount of Be in the magma is insufficient for the formation of gadolinite. These minerals will react according to the following scheme: thalenite + beryl $\rightarrow$ gadolinite.

2. The pegmatites rich in Calcium.

In some pegmatites, especially the pegmatites near Kragerø, the mineral parageneses are different from those hitherto described. These pegmatites contain some Ca-bearing, rare minerals as betafite, yttrotitanite, and hellandite, the formation of which is caused by a relatively larger amount of Ca in the magma. Pegmatites of this type are also

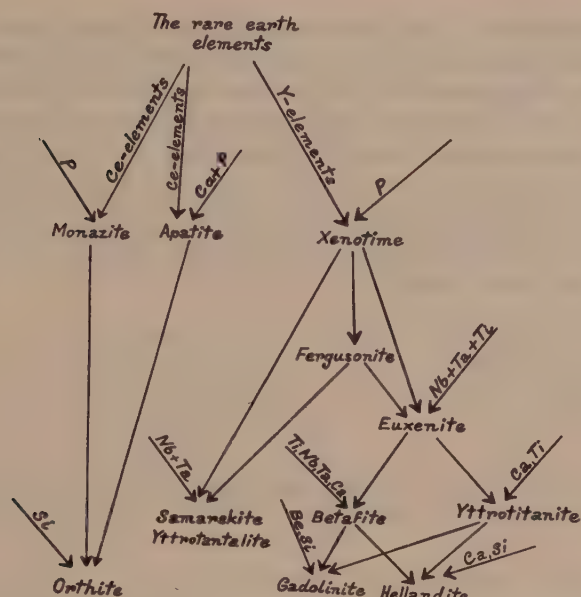


FIG. 4. Sequence of crystallization of the rare earth element-bearing minerals in the Ca-rich magmatic pegmatites.

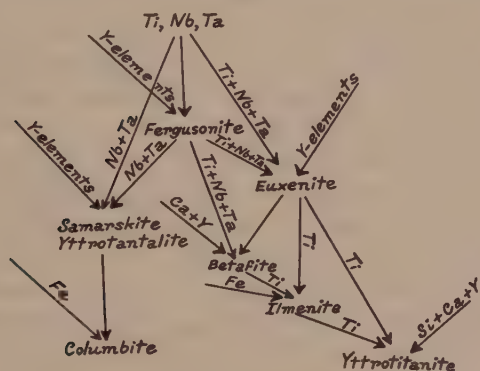


FIG. 5. Sequence of crystallization of the Ti, Nb, and Ta bearing minerals in the Ca-rich magmatic pegmatites.

richer in plagioclase and apatite. In these pegmatites monazite and Ca-silicates become unstable if the Ca-content increases beyond a certain value:



Other minerals characteristic of the pegmatites previously described are, under these conditions, partly replaced by Ca-bearing minerals of similar composition. Thus euxenite is partly replaced by the Ca-bearing niobate, betafite; and thalenite by the Ca-Y-silicate, hellandite. However, like thalenite, hellandite also becomes unstable together with beryl; hellandite + beryl $\rightarrow$ gadolinite. Hellandite, therefore, can form only if the amount of Be in the magma is insufficient to form gadolinite. The pegmatites rich in Ca may be subdivided into types corresponding to those of the Ca-poor pegmatites:

- | | |
|-------------------------------|-------------------------------|
| 1. PEGMATITES POOR IN CA. | 2. PEGMATITES RICH IN CA. |
| 1. Thalenite-gadolinite type | 1. Hellandite-gadolinite type |
| 2. Fergusonite type | 2. Fergusonite-betafite type |
| 3. Euxenite (samarskite) type | 3. Betafite type |
| 4. Columbite type | |

Thus far pegmatites rich in Ca corresponding to the columbite type have not been encountered among Norwegian pegmatites.

B. THE HYDROTHERMAL-PNEUMATOLYTIC PEGMATITES

These pegmatites occur as metasomatically formed dikes and veins in the magmatic pegmatites. The main mineral components are platy albite (cleavelandite), and quartz. Other common minerals are spessartite, a green and a lilac muscovite, and topaz. As distinct from the magmatic pegmatites, no obvious sequence of crystallization of the minerals was observed. Also in their chemical components the hydrothermal-pneumatolytic pegmatites differ from those of magmatic origin. The scarcity of rare earth elements causes Nb and Ta always to combine with Mn, Fe, and Ca. Some of these pegmatites are especially enriched in Ta, the characteristic minerals then being microlite and tantalite. In others Nb and Ta are present in about the same proportion as in the magmatic pegmatites, and the ordinary rare mineral is therefore a columbite. It is convenient therefore, to divide the hydrothermal-pneumatolytic pegmatites into two groups: (1) the microlite-tantalite pegmatites, and (2) the columbite pegmatites.

The minerals which occur both in the magmatic and in the hydrothermal-pneumatolytic pegmatites generally are present in different habits, and with different compositions in the two types of occurrences. Spessartite and apatite of the cleavelandite-quartz pegmatites usually occur in ill defined crystals intersected by blades of cleavelandite. They contain no detectable amounts of Y-elements, while those of the magmatic pegmatites usually contain these elements in considerable amounts. The columbites of the cleavelandite-quartz pegmatites differ from those

of magmatic origin by containing more Mn than Fe and they may, therefore, properly be called *manganocolumbites*. In Table 2 are given the relative intensities of the α -lines of the chief elements of columbites and a tantalite of different origin and localities, and the figures give a good picture of the relative variations in their composition.

TABLE 2. X-RAY ANALYSES OF NORWEGIAN COLUMBITES AND TANTALITES
Columbites and tantalites from hydrothermal-pneumatolytic formed
cleavelandite-quartz pegmatites:

	Relative intensities of the line					
	Fe $K\alpha_1$	Mn $K\alpha_1$	Ta $L\alpha_1$	Nb $K\alpha_1$	Ti $K\alpha_1$	W $L\alpha_1$
Manganocolumbite, Tangen, Kragerø	5	10	8	4	2	—
Manganocolumbite, Katterås, Iveland	6	10	8	5	0.5	3
Tantalite, Landås, Iveland	8	7	10	0.5	0.2	—
Columbite from magmatic microcline-pegmatite:						
Southern Norway:						
Columbite, Hulleknatten, Gjerstad	10	6	7	6	0.2	2
Columbite, Brokeland, Gjerstad	10	6	4	6	—	—
Columbite, Ramskjær, Søndeled	10	6	4	3	5	4
Columbite, Tveit 4, Iveland	10	6	4	5	2	6
Columbite, Tveit 3, Iveland	10	8	8	5	2	1
Columbite, Ljosland 1, Iveland	10	8	8	5	2	1
Columbite, Dalane 2, Iveland	10	5	7	6	2	3
Columbite, Rosås? Iveland	10	5	6	2	0.5	4
Columbite, Håverstad? Iveland	10	5	4	5	0.5	2
Columbite, Southern Norway	10	5	4	2	2	5
Columbite, Hitterø	10	5	5	5	0.5	1
Columbite, Øvre Vats, Ryfylke	10	6	7	5	1	4
Østfold, Southeastern Norway:						
Columbite, Ånnerød, Våler	10	6	0.5	7	—	—
Columbite, Lundeby	10	5	4	7	1	—
Columbite, Kure, near Moss	10	5	5	6	0.5	—
Columbite-tantalite, Karlshus, Råde	10	5	10	2	2	—
Columbite-tantalite, Halvorsrød, Råde	8	7	10	2	—	—

In some of the hydrothermal-pneumatolytic pegmatites are found also magmatically formed minerals as monazite, gadolinite, and beryl. These minerals represent remainders of a magmatic pegmatite which have been replaced by cleavelandite and quartz. Metasomatically formed beryl has been found only in the feldspar quarry at Halvorsrød in southeastern Norway, in small colorless euhedral crystals imbedded in fluorite and quartz.

TABLE 3. MINERALS FOUND IN NORWEGIAN GRANITE PEGMATITES

MAGMATIC	HYDROTHERMAL-PNEUMATOLYTIC
<i>Microcline</i>	
<i>Quartz</i> , milky or colorless	<i>Quartz</i> , colorless or smoky
<i>Plagioclase</i> (usually oligoclase)	<i>Cleavelandite</i>
<i>Biotite</i>	
<i>Muscovite</i> , colorless	<i>Muscovite</i> , green
<i>Scapolite</i>	<i>Muscovite</i> , lilac
<i>Spessartite</i> , in euhedral crystals usually containing small amounts of Y-elements	<i>Spessartite</i> , mostly in anhedral crystals without detectable amounts of Y-elements
<i>Tourmaline</i> , black	<i>Tourmaline</i> , black
	<i>Topaz</i> , in large crystals
<i>Beryl</i> , green, blue or yellow, in crystals up to 1000 kgms	<i>Beryl</i> , colorless, in small well-defined crystals
	<i>Phenakite</i>
<i>Chrysoberyl</i>	
<i>Gadolinite</i>	
<i>Thalenite</i>	
<i>Hellandite</i>	
<i>Kainosite</i>	
<i>Orthite</i>	
<i>Thortveitite</i>	
<i>Zircon</i>	<i>Zircon</i>
<i>Albite</i> (cyrtolite)	
<i>Fergusonite</i> (and risørite)	
<i>Ytrotantalite</i>	
<i>Titanite</i>	<i>Titanite</i>
<i>Ytrotitanite</i> (keilhauite)	
<i>Euxenite minerals</i> (including blomstrandine, polychrase, priorite)	
<i>Samarskite</i>	
<i>Betafite</i>	
<i>Mossite</i>	<i>Microlite</i>
<i>Columbite</i>	<i>Manganocolumbite</i>
	<i>Tantalite</i>
<i>Ilmenorutile</i>	
<i>Ilmenite</i>	
<i>Magnetite</i>	<i>Hematite</i> (martite)
<i>Uraninite</i> (incl. brøggerite and cleveite)	
<i>Thorite</i> and uranothorite	
<i>Apatite</i> , containing some Y-elements	<i>Apatite</i> , without detectable amounts of Y-elements
<i>Monazite</i>	
<i>Xenotime</i>	

TABLE 3 (Continued)

MAGMATIC	HYDROTHERMAL-PNEUMATOLYTIC
<i>Bismuthinite</i>	<i>Triplite</i> ¹
<i>Native bismuth</i>	
<i>Molybdenite</i>	
<i>Pyrrhotite</i>	
<i>Chalcocite</i>	
<i>Bornite</i>	
<i>Calcite</i>	
	<i>Fluorite</i>
	<i>Parisite</i>

As secondary minerals there occur albite, epidote, chlorite, kaolinite, tenerite, molybdenite and bertrandite.

¹ The first find of triplite in Norway was made last year in the microlite-and tantalite-bearing pegmatite at Landås, Iveland.

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A MINERALOGIC STUDY OF SILICOSIS*

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ABSTRACT

Silicosis is caused by the presence of colloidal silica in the tissues of the lung. Such silica apparently destroys living tissues by collecting on cell walls. Its source is believed to be inhaled particles of quartz and silicates which remain in the lung long enough for the mildly alkaline lung fluids to attack them chemically. The removal of such dust particles from the lung is facilitated by the presence of other dust particles which serve as flocculating agents. It is recommended that if such protector dusts are not present in an environment where the silicosis hazard prevails, then they should be added as an economical and effective means of protection. The suggestion is also made, based on experimental data, that other minerals not yet recognized may create similar health hazards. A microscopic examination by a competent petrographer should be made to determine what protector dusts are needed in a given case.

The attention which has accrued to the silicosis problem, stimulated by humanitarian and scientific interest as well as by the commercial demand for prevention through control of conditions, is in a measure justification for the entrance of more petrographers into the field in a co-operative attempt to contribute to a solution. Since the materials which cause silicosis are mineralogic and petrographic in nature, and since experimental backing for a suggested preventive method involves the study and handling of mineralogic and petrographic materials and technique, it is proper to remove this part of the burden from the physiologist in the interest of efficiency and economy of time. The results of the study presented here were obtained after repeated consultations with Drs. Middleton, Bunting, and McCarter of the faculty of Medicine of the University of Wisconsin. We wish, also, to acknowledge the helpful cooperation of Professor E. Truog of the University of Wisconsin, Department of Soils, and of Professor E. B. Fred and J. L. Roberts for extending the use of the facilities of the Agricultural Bacteriology department.

The literature on the subject is so extensive and has been collected so effectively by others more competent to do so in the medical field, that no attempt is made here to do more than give occasional pertinent references.

Outstanding conclusions of others which should serve as a basis for further work are two: First, that silicosis is caused by the liberation in the lung of colloidal silica by minerals able to produce it in that specific

* Presented December 29, 1936, at the annual meeting of The Mineralogical Society of America held in Cincinnati, Ohio. This work was supported in part by a grant from the Wisconsin Alumni Research Foundation.

environment;^{1,2} Second, that certain materials, notably shale, have been observed to exercise a protective influence in the lung on those exposed to the silicosis hazard.^{3,4} It is logical, then, to direct further work along lines which connect these two conclusions. The thesis of this paper is that certain minerals, which are present in shale, and elsewhere, have a protective influence in an environment which is otherwise conducive to silicosis.

The theory adopted here for the cause of silicosis is briefly as follows: A mineral particle in the lung is submerged in a mildly alkaline solution which slowly dissolves any particle of the nature of quartz, which is susceptible to alkaline attack. Since considerable time may elapse before such a particle may be expelled from the lung, the chemical attack, especially for some minerals, becomes quite effective. The silica thus liberated is either in true solution or in a colloidal suspension, probably both. This silica is dispersed radially outward and collects on the walls of nearby cells, which become "smothered" by the adhering silica film. Their function is destroyed and the cell dies. This dead cell tissue is then replaced by connective tissue which constitutes the silicotic nodule. Since the dispersed silica radiates outward from the mineral source the immediately adjacent cells are the first to be destroyed. Until the adjacent cells collect their quota of liberated silica, more remote cells are unaffected. Therefore, the nodular growth forms from the center outward, in surface layers much like the skins of an onion. These constitute the whorls commonly seen.

On the basis of this theory the immediately noxious substance is the dispersed colloidal silica, and not the foreign particle which is the source of it. It is obvious that any mineral which is susceptible to attack by the mildly alkaline solutions in the lung, with the liberation of silicic acid, is also capable of causing silicosis unless the dispersion of the liberated silicic acid can be prevented. Let us first view another aspect of the problem.

The lung is equipped with means of eliminating foreign bodies which reach even the remote air sacs beyond the bronchioles. This means consists of amoeboid scavenger cells known as phagocytes which engulf such bodies and then convey them from the lung. This phagocytosis functions variously on different materials. If it functions properly there is inadequate time ordinarily for the effective chemical attack on the foreign body. This kind of protection is then to be emphasized especially.

Haldane and his associates⁴ have demonstrated that the lung does not eliminate all mineral materials with equal ease. Pure minerals are eliminated with difficulty; certain mixtures are eliminated much more easily.

Pure lamp black ("flue dust"), "pure china clay," and pure quartz are difficultly eliminated. On the other hand, most coals are relatively easily eliminated, as are mineral mixtures which include shale. Haldane has called attention to the influence of shale as a protector against silicosis. Mavrogordato⁵ used coal dust as an "antidote" for silica dust in guinea pigs. Haldane, with his wealth of experience states,⁴ "There seems to be little doubt that when a mineral which, owing to the presence of much quartz, gives a naturally dangerous dust, is mined with country rock of another character which has to be worked simultaneously, the danger from the quartz may be almost abolished."

There seems to be ample reason to believe, therefore, that protector minerals exist. If a sound explanation can be found, then the protector minerals may be identified. By way of explanation Haldane stated in 1917.³ "It can well be imagined that insoluble dust particles are attractive to dust cells in proportion to the soluble substances adsorbed in the dust particles, and that the particles containing little of these substances will be correspondingly unstimulating." Again in 1929⁴ Haldane stated, "Why then do some kinds of dust stimulate the dust cells? It must be, I think, because they are either themselves soluble or contain something soluble and thus capable of acting as a stimulant." This explanation is as Haldane says, "still more or less obscure."

Doubtless there are many factors which control phagocytosis. It seems reasonable that if one dust, such as shale dust, is stimulating to a phagocyte then that dust should be selectively removed and the unattractive quartz dust left behind. But in presence of such a protector dust, *both* dusts are removed. The following explanation, therefore, is suggested as the factor of paramount importance.

Cataphoresis runs have been made on many such substances as those discussed here and were repeated for this study. It is known that silica in a dilute sodium chloride water solution carries a negative charge. Other substances, similarly, carry a positive charge, notably carbon as carbon black, iron oxide as hematite, and the alkaline earth carbonates. In the presence of these oppositely charged materials the whole is aggregated by virtue of this attraction and thus loses its disperse state (It has been reported that both quartz and carbon, and possibly other such substances are reversed in charge by the adsorption of proteins in the lung fluids. The principle still holds.) Koppenhofer calls attention to the similarly neutralizing effect of aluminum hydroxide sol on colloidal silica.⁶

The inhalation of pure mineral materials, whether carrying a positive or a negative charge, leads to disperse distribution,—masses of particles,

mutually repellent and in a state of open packing. The forces which hold such particles apart are not commonly appreciated for their full worth—they are real forces. In a purely mechanical way, phagocytosis of such disperse material is difficult. The carrying capacity of individual phagocytes is thus cut down, and we say the lung cannot eliminate such pure material. On the other hand, mixed minerals of positive and negative charges form flocculated aggregates—particles in a state of close packing, many more of which may be handled by one phagocyte, since a given volume contains more particles.

The following simple experiment illustrates the flocculating action. To three settling tubes of freshly prepared serum (beef serum was used by us) add three powders of suitably fine size. To one add quartz powder, to the second add carbon black which has been rendered oil free by washing with alcohol, acetone or a similar oil solvent, and to the third add a mixture of the two. Each powder should be previously wetted with water under partial vacuum to eliminate air bubbles and films. Two or three hours after mixing the wet powders and serum, the mixed powders will be found to have settled much farther than the others.

Since shale is a rock and not a mineral, but an assemblage of minerals, and since one prominent constituent of shale is quartz, then on this basis shale is a very inefficient protector to add to noxious dust. Some of the constituents of shale are harmful, some are protectors. The protectors are, we believe, those which carry the opposite charge in lung fluids to that carried by quartz. These protector minerals if added alone to noxious dust should, therefore, be much more effective than shale.

Sometimes a lung builds a wall ("capsule") around masses of foreign particles. Such isolated masses will not be affected by the addition of a protector dust. Thus Mavrogordato says,⁵ "If silica dust be given to an animal who has previously inhaled coal dust, the presence of the coal does not stop the arrest of the silica. If coal dust be given to an animal who has previously inhaled silica dust, the coal does not fetch out the silica. For beneficial results the silica and 'antidote' must be inhaled simultaneously."

Let us separate the fact from the theory. That protecting elements exist is, we believe, definitely recognized. Though shale is one of them, it helps but little since shale is itself a mixture of noxious and protector elements, and, further, no two shales are identical in composition. Some shales which the senior writer has studied for their silicosis hazards he believes would offer no protection whatever, in fact they contain almost exclusively noxious minerals. Calcareous shales, on the other hand, we believe are real, but not efficient, protectors. It has been demonstrated

experimentally that certain *pure* minerals are *not* readily eliminated from the lung. It has also been demonstrated experimentally that certain *mixtures* are readily eliminated from the lung. The theoretical explanation offered here is that flocculated, or aggregated foreign bodies may be eliminated by phagocytosis while disperse bodies may not. Our aim is to accomplish the aggregated state by mixing suitable dusts with noxious dust to facilitate the elimination process. We define suitable dusts as those which carry in the lung fluids a charge which is opposite to that carried by noxious dusts. There are experimental and other reasons to believe that the protector dust functions best when inhaled *with* the noxious dust. Next we shall indicate our further belief that there is some benefit from the delayed inhalation of protector dusts.

On the assumption that the dispersion of silica is the immediate cause of the formation of a silicotic nodule, it is reasonable to believe that if the liberated silica can be conveyed from the lung there will be no harmful effect. But we think of phagocytosis as a process primarily to eliminate sizeable foreign bodies rather than material of colloidal dimensions. If, however, the colloidal material is flocculated to form aggregated masses or adsorbed films on solid bodies, then it constitutes a tangible mass on which the phagocyte may function. In other words, the phagocytosis of colloidal or dissolved silica seems not to take place unaided. Furthermore, the noxious element, colloidal silica, is robbed of its potency while flocculated.

How then may the silica liberated from minerals which the lung has not been able to eliminate, be prevented from spreading? There are many circumstances, of course, when such prevention cannot be accomplished. If, however, any of the protector dust particles are near the source of colloidal silica they constitute a strong attraction for the free silica just as they do for the coarser dust particles. They may be expected, therefore, to serve as collectors for at least some of this liberated silica, retaining it as a discrete unit. Mavrogordato has shown that "silica-stricken" areas of animals' lungs selectively arrest inhaled carbon dust.⁵ It is obvious that such protector dust particles will be of greater protection the closer they are to the source of silica being liberated. Hence the double advantage of inhaling protector dusts along with noxious dust. Such protector dust is itself a sort of scavenger to free colloidal silica and as such, doubtless yields some benefit, even though not inhaled along with the noxious dust.

Coal is not a reliable carbonaceous dust to add. The charge carried by a coal particle depends upon the customarily recognized factors, but also upon its ash content. This is the apparent reason that coal is usually

eliminated from the lung. A pure coal, if such there is, like carbon black would doubtless be retained by the lung.

Haldane has cited Cripple Creek, Colorado, where calcite is a constituent of the ores, as a locality where silicosis is not a serious problem despite the silica content of the ore. We point to the calcite as a protector mineral.

At Mysore, India, where the ore is high in ferromagnesian minerals, silicosis is not so serious as expected, though there is some doubt cast on these statistics. The Geological Survey reports of India indicate the presence of carbonates as well as ferromagnesian minerals which may serve as protectors.

Since rock drilling is rarely done in uniform material, it is both difficult and hazardous to state that a given case has resulted from a given dust. Irregular occurrences of silicosis, where the rock seems safe, need explanation. Stewart and Faulds recent report on pulmonary fibrosis of hematite miners⁷ is such an example. Possibly the relative strength of charges is the controlling factor at times. It is inevitable that the phosphate content of some hematite ores, a recognized adsorption phenomenon, modifies the quantity if not the quality of the charge the mineral will carry. And a natural corollary of the views expressed here is that a reversal of the charge of the protector mineral by any unforeseen factor renders its part detrimental rather than beneficial. It is impossible yet to evaluate other factors which may easily control in a given instance. Of fundamental importance, however, are experiments such as those of Mavrogordato who showed that flint dust was retained in animals' lungs whereas mixtures of flint and coal dust were not so retained. More such work is needed to learn what other influences may enter to prevent this flocculating action of apparently suitable mineral mixtures.

SOLUBILITY OF SILICATES

At the suggestion of Dr. W. S. Middleton, and with these ideas in mind, an experiment was formulated to test the susceptibility of minerals to attack by such solutions. A group of fourteen commonly occurring silicate substances was treated with blood serum over a period of two months. The underlying assumption is that any mineral which may liberate silica under such conditions may do so if introduced into the lung. The details of the experiment follow.

Pure mineral materials were first obtained when possible. Impure minerals were purified in order that any results obtained could be attributed to one material alone. The mineral was first crushed, then ground in a mechanical steel mortar. The ground material was sized by

allowing it to settle in distilled water a suitable period of time. The material in suspension was then decanted and the solid material mainly centrifuged out, and oven dried at 100°C. This was examined under the microscope to check the size. Resizing was done when necessary to limit all to a size range of 1μ – 10μ . In the case of platy and fibrous minerals one dimension is commonly greater than 10μ but the thickness of such flakes is near 1μ – 3μ . The time and speed of centrifuging were controlled to eliminate material below 1μ in the final product. By repeating the centrifuge procedure a number of times it was possible to get a powder virtually free from particles less than one micron in diameter.

This sized material, if hard, invariably contained iron from the mortar, which had to be removed. This was done in two ways. In one method the iron was dissolved by use of strong HCl and the resulting FeCl_3 rinsed out by repeated centrifuging. From those minerals which are more susceptible to attack by strong HCl, the iron was removed by bubbling H_2S gas through the suspension and then dissolving the FeS with N/20 HCl according to the procedure of Drosdoff and Truog.⁸

Minerals which were impure, notably the sericite used, were purified gravimetrically. This consists in floating off the lighter constituent with a heavy liquid. The procedure is as follows:

The dried powder is placed in a flask and the flask evacuated. Bromoform, diluted with acetone, is introduced under vacuum after which air is admitted. This gives thorough wetting and thereby enables each particle to behave as a discrete grain, and not as a member of an aggregate. The gravity of the liquid is adjusted to lie between the specific gravities of the minerals to be separated. The suspension is then centrifuged—one constituent floats and one sinks. The floating cake is decanted. Microscope examination was used to check the purity. It was sometimes necessary to go through the procedure twice. The gravimetric purification was done on the crushed powder before fine grinding. Only purified material was ground, with the exception of augite, which contains a little chlorite, a very common alteration product which was not removed.

The purified, ground, and sized material was next placed in pyrex flasks for treatment with serum. As an added precaution to insulate the inside of the flasks from possible solvent action of the serum, they were previously coated with a film of "gelva," a commercial resin. To accomplish this a syrupy solution of gelva in acetone was prepared and applied to the inside of the flasks. This dried for several hours, was baked at 110°C. for several hours more and finally roasted carefully over a gas burner to a light brown color. The resulting film, though not completely successful, remained intact on most of the flasks throughout the experiment. In the flasks containing quartz (2), biotite, talc (1), microcline

and sillimanite, the film broke sufficiently to expose some of the glass during the last week or two of the run. We feel that the glass surface thus exposed is negligible compared to the surface exposed on the mineral powder, and that the influence on the final results is small.

A weighed amount of each mineral powder was placed in the coated flask, stoppered with cotton and sterilized in an autoclave for an hour. The serum used in the experiment was obtained from beef and human blood in the following manner: The warm blood was exposed to the air momentarily to cause clotting, and then covered and placed in the refrigerator for a period varying from several hours to twenty-four hours. The clear serum was poured off, and before its introduction into the flask, a sample was taken upon which the pH was determined with the glass electrode.

Serum was introduced into the sterilized flask by filtration through a bacteria-proof filter, which had been sterilized in the autoclave and transferred to the flask over a strong flame in a steamed room with the customary precautions against bacterial contamination. The serum was then drawn through the filter into the flask and when the desired quantity had been introduced, the filter was removed and a sterilized coated cork introduced into the mouth of the flask and sealed with beeswax.

The sealed flasks were placed in a water bath where the temperature was held at $37.5^{\circ}\text{C.} \pm 0.5^{\circ}\text{C.}$ The flasks were attached to a central rod, adjusted to oscillate back and forth 100 times per minute, and were kept in the water bath for a period of two months.

After removal from the bath at the end of two months the flask was opened and a sample taken to determine the pH of the serum. The remainder was centrifuged at 3500 RPM for 15 minutes to throw down the mineral particles. The supernatant liquid was poured off and analyzed for silica.

The procedure of the analysis was as follows:

About 10 cc. of concentrated $\text{Mg}(\text{NO}_3)_2$ solution was thoroughly mixed with 100 cc. of the serum in a platinum evaporating dish and placed on a hot plate at about 70°C. for 12 hours. It was then heated slowly over a burner till the nitric oxide fumes had been completely driven off, after which it was ignited at high temperature. The resulting fluffy powder was treated with concentrated HCl and diluted with water before filtering. The filtrate was evaporated on the hot plate and dehydrated in the oven at 110°C. for one and one-half hours. The dehydrated mass was again treated with concentrated HCl and water to dissolve the chlorides, and then filtered through a new filter paper. The two filter papers, washed with warm 1% solution of HCl , were combined and ignited in a platinum crucible.

The crucible and contents were weighed, and then treated with HF and H₂SO₄ acids and placed on the hot plate to evaporate. After ignition the crucible was again weighed and the difference in weights taken to be the weight of SiO₂.

In the analysis of the serum the sample was usually split into two aliquot parts, and each part analyzed separately.

Mineral	Size range (microns)	Sample weight (gms.)	Vol. of serum (cc.)	Type of serum	pH at 25°C.		SiO ₂ dissolved (%)
					before run	after run	
Quartz (1)	1-12	10.041	200	Human	7.60	6.90	0.100
Quartz (2)	1-12	10.463	200		7.55	7.14	0.080
Opal	1-10	10.434	120		7.72	7.21	0.100
Sericite	2-15	10.029	140		7.88	6.71	0.195
Asbestos (amphibole)	1-15	9.438	140		7.56	7.31	0.120
Cristobalite	1-10	10.738	200		7.35	7.10	0.076
Sericite	2-15	8.962	180		7.60	7.05	0.185
Biotite	2-20	8.142	200		7.62	7.30	0.123
Asbestos (amphibole)	1-20	10.735	150		7.40	7.04	0.105
Glass (optical)	1-12	10.803	250		7.59	7.20	0.085
Talc (1)	2-20	8.912	190	Beef	7.65	7.31	0.104
Talc (2)	2-20	10.410	200		7.52	7.45	0.091
Microcline	1-10	10.772	220		7.48	6.72	0.045
Bytownite	1-10	11.888	190		7.53	6.92	0.060
Garnet (almandite)	1-10	10.156	150		7.62	7.41	0.052
Augite	1-10	9.856	220		7.56	7.39	0.055
Tourmaline	1-10	8.475	150		7.60	7.02	0.069
Sillimanite	1-10	6.722	200		7.62	7.21	0.065

To give a measure of the amount of colloidal SiO₂ liberated from each mineral, the weight of dissolved SiO₂ was compared with the original weight of the mineral sample and the percentage of dissolved SiO₂ calculated.

No allowances were made for the factors involving variations in pH, or the size frequency distribution of the particles within the set limits. The influence of the first factor is not wholly known, but that of the latter is probably appreciable.

The results of these experiments are given in the table and graphically in figure 1. Although these results are not infallible and the method by which they were obtained somewhat arbitrary, they indicate certain things. All the materials which yielded a greater percentage than .075% of silica, with the exception of biotite, have been suspected of producing silicosis. Biotite is in some ways similar to talc and sericite,

which throws suspicion on minerals of the mica type. Outstanding of course is sericite, and the attention given to this mineral as a cause of silicosis is supported by this work. To many of us who regarded the mere presence of sericite in the lung on incineration as evidence that it was

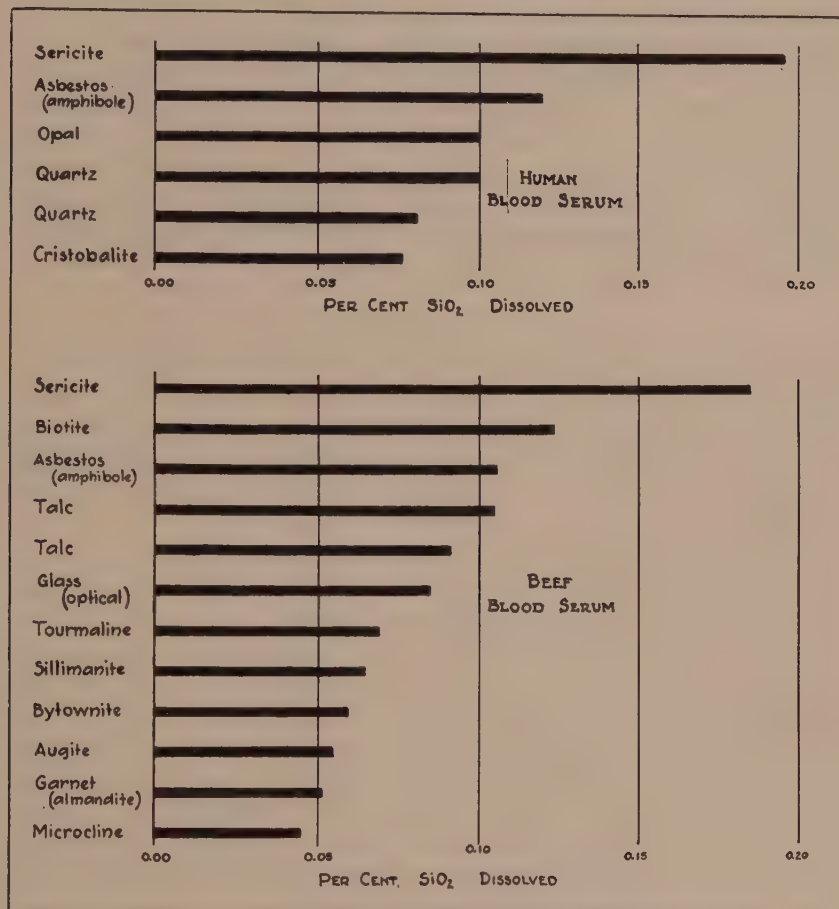


FIG. 1. The length of the line opposite a mineral name indicates the amount of silica dissolved by the blood serum, the mineral being powdered and the mixture agitated at body temperature for two months.

harmless (otherwise it would have been consumed), its silica yield here is most arresting. At the present time we cannot say more. In general these results indicate the desirability of further experiments of this general type to learn what other minerals may release colloidal silica in body fluids.

Koppenhofer⁶ cites animal experiments by Giese in which injected kaolin suspension led to no harmful effects on the animals, and suggests that the aluminum hydroxide, set free simultaneously with the silicic acid and oppositely charged, renders the silicic acid harmless. Somewhat the same process may take place with sericite and other silicates containing aluminum, for Lemon and Higgins,⁹ and Fallon and Banting¹⁰ injected sericite suspensions into animals with little or no harmful results. Feil¹¹ has noted the absence of silicosis in slate quarry men exposed to a high concentration of sericite dust. If, together with the large amount of silicic acid released from sericite, as shown in the above solubility experiment, a correspondingly large amount of oppositely charged aluminum hydroxide were liberated, the two might act as mutual flocculating agents and enable the silicic acid to be removed.

SUMMARY

Three substances are selected here as suitable protectors—carbon black, iron oxide (hematite), and alkaline earth carbonates. We believe that they are able, first, to render silica dust more easily eliminated by the lung, and, second, to protect the lung from the effect of colloidal silica liberated by proximate minerals which the lung has not been able to eliminate.

The idea here advocated is to add to a noxious siliceous dust one or more of these protector minerals, as a dust for an effective and economical means of rendering the noxious dust harmless. The question of grain size of the added dust immediately arises. The object is to maintain an adequate amount of the finer sizes (less than 10μ) since only these are effective. If we may use the reported effect of shale as a measure, then 20% of the protector mineral is adequate, but this refers only to the finer sizes, which means that less than 20% addition to the whole original dust is needed. The proper procedure seems to be a careful microscope examination of the dust in question to learn size-distribution and mineral content. This should dictate the kind and amount of protector dust to add. It should be borne in mind that the finer dusts are being re-supplied from the coarser ones ordinarily and are also being blown away. Experiment and experience will teach the details of the quantity of protectors needed.

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BUILDING NUCLEAR CRYSTAL STRUCTURE MODELS

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ABSTRACT

Herein appears a detailed description of a simplified method for building nuclear crystal structure models of any complexity. As a basis of explanation the building of a sanidine model serves as the guide; brief remarks are given on a muscovite model and color schemes.

Crystal structure models are valuable in introducing the beginning student to the intricacies of the subject, even though some advanced workers in the field may be able to dispense with them. Models of this kind are of two types, which may be designated as nuclear models and packing¹ models. The latter are commonly balls of sizes proportional to those of the atoms or ions concerned which are in contact with at least some of their neighbors; they are valuable to show types of packing, to elucidate morphotropic changes, and to indicate "cavities" in the structure. But some of them (e.g., quartz) are commonly built so that balls are linked together with rods where there is actually no coordination, and the interior of "tight" structures cannot readily be discerned. Nuclear models are made of balls of much smaller size, spaced relatively widely along a wire network; thus each ball can be taken to represent the nucleus of the atom or ion concerned. They are particularly useful in demonstrating coordination relations, bond angles, and types of bonding such as Machatschki advocated be used in classifying the silicates. They are excellent aids in clarifying the explanations of such physical properties as cleavage² and hardness. They may be used for graphically determining the necessary angles for making packing models, or for checking such calculations made analytically. The original calculations necessary to build the model are much simpler than is true for packing models. It is easy to indicate the unit cell on them. Another kind of model which may be regarded as a modification of the nuclear type may be called the polyhedral nuclear model; in this the coigns of polyhedra

¹ Buerger, M. J., and Butler, R. D., A technique for the construction of models illustrating the arrangement and packing of atoms in crystals: *Am. Mineral.*, vol. **21**, pp. 150-172, 1936.

² For example, see Shappell, M. D., Cleavage of ionic minerals: *Am. Mineral.*, vol. **21**, pp. 75-102, 1936.

nuclear and of polyhedral nuclear models are much more common than are taken to represent the positions of ions.³ Combinations of strictly the purely polyhedral kind, which are suitable for only such substances as silica.

The above discussion serves to indicate that no one type of model is entirely satisfactory for all purposes. For general use, and particularly for the instruction of beginning students, it is desirable to have different types of models of the same crystal structure. Where the structures are simple, with a small number of atoms in the unit cell, it is practicable to have both nuclear and packing models on the same scale. For more complicated models such as muscovite, which while the unit cell has but 76 atomic positions, must contain some 300 atomic positions if it is to be really effective in showing the sheet structure, it is impossible to make a nuclear model by the method herein described on a scale much smaller than 2.4 cms. to 1 Å. While the writers know of no packing model of muscovite, presumably one could be made to advantage on a scale considerably smaller than this.

The object of the present note is to describe a modification of the scheme given by Gruner,⁴ thus enabling relatively untrained workers to build nuclear models of considerable complexity with a high degree of accuracy. A model can be made very easily by attaching balls to vertical pegs or rods at appropriate places. But for most structures, a model of this kind has its essential features obscured by these rods, which have no structural significance. The method herein described makes use of such rods during construction, but they are eliminated in the completed model.

For purposes of illustration, the building of a sanidine model according to the analysis of Taylor⁵ will be described. Fig. 1 is a reduced copy of the plan used in building the model. It is really a projection of the

³ The ion commonly at the polyhedron center is ordinarily not visible, unless transparent material as glass or celluloid is used in fabricating the polyhedra. The polyhedra degenerate into planes in making this type of models of nitrates, carbonates, and of other substances with "plane" radicles; e.g., K_2PtCl_4 . Polyhedral nuclear models are shown in the *Strukturbericht*, 1913-1928 (e.g., p. 234) and are figured very frequently in E. Schiebold: *Kristallstruktur der Silikate*, in vols. 11 and 12 of *Ergebnisse der exakten Naturwissenschaften*.

⁴ Gruner, John W., A new method of building crystal structure models: *Am. Mineral.*, vol. 17, pp. 35-37, 1932.

⁵ Taylor, W. H., The structure of sanidine and other feldspars: *Zeit. Krist.*, Vol. 85, pp. 425-442. 1933. Also see Taylor, Darbyshire and Strunz: An X-ray investigation of the feldspars: *Zeit. Krist.*, Vol. 87, pp. 464-498, 1934.

coordinates⁶ of the ions of the sanidine unit cell on a plane through the lower front edge of the unit cell perpendicular the *c*-axis. The numbers near the points located refer to the heights of the ions concerned above the baseboard on which the plan is mounted with thumbtacks. These numbers⁷ are given in terms of centimeters on the basis of 1 Å=2.4 cms., or an enlargement of 240,000,000 times. This is somewhat smaller than the scale advocated by Gruner, and appears to be rather more satisfactory. It is based on the fact that with this scale an ordinary tennis ball can be used to represent an oxygen ion of radius 1.32Å.

⁶ Taylor, *Op. cit.*, p. 430. Taylor's values, in Ångstrom units, are given below, together with the corresponding values in cms., based on the scale 1 Å=2.4 cms.

Ion	Number in unit cell	Axial Coordinates							
		<i>x</i>		<i>x'</i>	<i>y</i>		<i>z</i>		<i>z'</i>
		Å	cms.	cms.	Å	cms.	Å	cms.	cms.
O ₁	4	0	0	0	1.79	4.3	0	0	8.9
O ₂	4	5.53	13.3	11.9	0	0	1.68	4.0	7.1
O ₃	8	6.90	16.6	14.9	1.97	4.7	1.68	4.0	5.7
O ₄	8	0	0	0	4.12	9.9	1.78	4.3	13.2
O ₅	8	1.28	3.1	2.8	1.61	3.9	2.96	7.1	14.7
K	4	2.47	5.9	5.3	0	0	0.99	2.4	8.7
Si ₁	8	0	0	0	2.40	5.8	1.54	3.7	12.6
Si ₂	8	5.90	14.2	12.7	1.43	3.4	2.47	5.9	8.6

These coordinates are in terms of a unit cell with $a:b:c = 8.45:12.90:7.15\text{Å} = 20.28:30.96:17.16\text{ cms.} = 0.655:1:0.554$ (axial ratio), and $\beta = 63^\circ 54'$. The *x* coordinates are measured parallel to the inclined *a*-axis; hence each value must be multiplied by $\sin \beta$ to change it to *x'*, which is the corresponding distance in the horizontal plane. Thus the apparent length of the *a*-unit becomes 20.28 cms. $\times \sin \beta = 18.25\text{ cms.}$ in the plane of the drawing, Fig. 1. The *z* coordinates are measured parallel to the vertical *c*-axis, but from the inclined plane forming the base of the unit cell; to change these to *z'*, which are the corresponding distances measured from the horizontal plane, each value of *z* must be increased by adding $\cot \beta \times (18.25 - x' \text{ cms.})$.

In the above table coordinates are given for only 8 ions. The coordinates of all additional ions within the unit cell are obtained from the original set through the operations of the symmetry shown in Fig. 1.

The axial coordinates given by Wyckoff (*Structure of Crystals Supplement*, 1935, p. 126) appear to differ from those in the above table because the former are stated in terms of decimal parts of the unit cell dimensions. In some papers the positions of the unique ions of a unit cell are described in terms of angular coordinates θ_1 , θ_2 , and θ_3 . These are used in structure determinations for calculating the scattering power (*F*) of the various ions. These can be converted to axial coordinates by means of the following formulae: $\theta_1 = 2\pi x/a$; $\theta_2 = 2\pi y/b$; $\theta_3 = 2\pi z/c$.

⁷ In building the model it is convenient to add 5 cms. to each of these numbers to allow room for working below the base of the unit cell.

By means of a drill press, holes of a diameter to fit tightly B. and S. gauge no. 11 brass wire (just under $3/32$ inches in diameter) are bored at the indicated points in the baseboard to a depth of 1.6 cms. Lengths of this wire corresponding to the largest number by each hole (adding 1.6



FIG. 2A

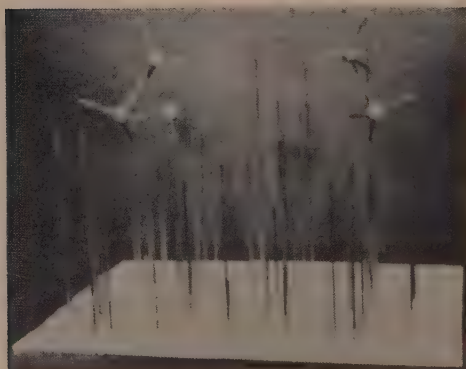


FIG. 2B

FIG. 2. *A* (above): Peg model of sanidine, initial stage. *B* (below): The same, after completing five SiO_4^{-4} tetrahedra. Plastic wood balls indicate the positions of the five Si^{+4} ions.

cms. in each case) are driven into the baseboard forming the peg model shown in Fig. 2A. At this stage the top of each peg represents the center of the highest ion in each position that is to appear in the model. While the plan of Fig. 1 outlines but a single unit cell, the model as actually built is somewhat larger than this. This extension laterally is easily carried out by means of translations of the plan in the *a*- or *b*-directions

by distances equal to the unit in these directions, the length of the a -unit of course being foreshortened and so appearing as $\sin \beta$ times the true a -unit.

It was found to be easier and more accurate to make rods representing



FIG. 3A

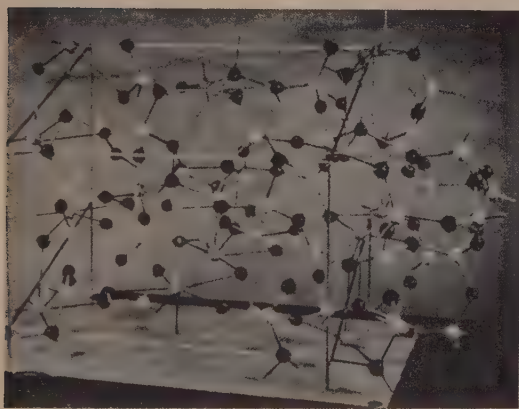


FIG. 3B

FIG. 3. *A* (above): Same as Fig. 2*B* except that all of the SiO_4^{-4} -tetrahedra of the unit cell have been completed and parts of the unit cell are outlined. *B* (below): The completed sanidine model. The morphological c -axis is vertical; the 2-fold, horizontal.

coordinations long enough to tie 3 ions together, no more no less. Thus the higher SiO_4^{-4} -tetrahedra were built first by cutting pieces of brass rod a trifle longer than 7.78 cms. (to allow for the overlap at the silicon ions), and bending them in the middle at angles of slightly under $109\frac{1}{2}^\circ$.

Before any soldering many rods were so cut and bent by gripping in a small vise, or simply holding in a pair of pincers and pressing the free side down against a board or the table top. Two such rods crossing at the bends serve to build the framework of a SiO_4^{-4} -tetrahedron. One rod is held by an end at the top of an "oxygen peg" with its bend on the top of a silicon peg and while in this position its far-end is soldered to the top of a suitable oxygen peg, using a flux on the top of the peg and the end of the rod. The peg whose top marks the position of the Si^{+4} -ion is then with a pair of nippers cut off at the next lower level shown on the plan, after marking the proper place with a pencil line, located by measuring up from the baseboard the indicated distance. Another bent rod is held across the first one so that the bends meet at the Si^{+4} -ion position and the two ends rest on the tops of the proper oxygen pegs. After fluxing, the two rods are soldered together at their bends which location marks the position of the Si^{+4} -ion at the center of the SiO_4^{-4} -tetrahedron. It is also advisable to "tack down" with solder one of the free ends of the second bent rod at the top of one of its oxygen pegs. The two oxygen pegs which now have the ends of two bent rods resting on but not attached to them are next cut down to their lower levels as was done for the silicon peg. To one of the free ends of the wire SiO_4^{-4} -tetrahedron thus completed is soldered the end of a new bent rod while its bend rests on the top of a Si^{+4} -peg and its other end is held at the top of a suitable oxygen peg. Then this second tetrahedron is finished in the manner described above. Fig. 2B shows the condition of the model after five such tetrahedra have been completed. Plastic wood balls have been added marking the positions of the Si^{+4} -ions. Moreover in two places where the two rods from an O^{-2} -ion position to two Si^{+4} -ions make a large angle (about 160°) with each other, small cross-pieces have been soldered at the junction of the two bent rods, so that when later the plastic wood ball representing an O^{-2} -ion is added, it will have no tendency to slip.

Fig. 3A shows the appearance of the model when this process has been continued until all the SiO_4^{-4} - and AlO_4^{-5} -tetrahedra have been completed. Plastic wood balls mark the locations of the Si^{+4} - and Al^{+3} -ions, and the top as well as half of the base (in the b -axis direction) of the unit cell is shown by wires. The seven remaining pegs mark the positions of the K^{+1} -ions.

The unit cell with four molecules of KAlSi_3O_8 must carry four Al^{+3} -ions. The positions of these can not be differentiated from those of the Si^{+4} -ions by X -ray data. Since the sixteen (Si^{+4} -plus Al^{+3} -ions) occur at the points of two general positions designated Si_1 and Si_2 , in the table in footnote 6, each of which carries eight ions, there is no way of putting four

Al^{+3} -ions in the unit cell without destroying some of its symmetry.⁸ A statistical distribution must be assumed. In making a model one has the choice of using one color of ball to designate the two kinds of ions, or he may color all the balls in either one of the two general silicon positions half aluminum paint and half the color (white) used to designate silicon, or he may arbitrarily select half the balls of either position to represent Al^{+3} -ions. The last course was followed in painting the model depicted in Fig. 3B, and the four " Si_2 balls" nearer the center of the unit cell were so chosen, as close examination will show. This satisfies all elements of symmetry except the screw axes, glide planes, and the symmetry centers lying in the latter. It serves to emphasize how difficult it is to make a static model furnish a close picture of that dynamic body we call a crystal.⁹

Having completed the framework structure of the sanidine model, it is but a fill-in job to add the positions of the K^{+1} -ions. These occupy large spaces in the structure and coordinate with ten O^{-2} -ions. They are 6.8 cms. (2.84 Å.) from six of these and 7.6 cms. (3.16 Å.) from the other four. These two types of coordination are differentiated on Fig. 1. Accordingly two sizes of wire are used, both smaller than that used for the SiO_4^{-4} -framework (the stronger the bond, the coarser the wire in general).

Extension of the structure by methods already described a bit beyond the boundaries of the unit cell, addition of the remaining wires¹⁰ to show the outline of the unit cell (those parallel the c -axis extend below the unit cell to serve as a base), completion of the plastic wood balls, and painting serve to finish the model to the form depicted in Fig. 3B. The whole process is so simple that given a plot such as shown in Fig. 1 any

⁸ This symmetry is indicated in Fig. 1. A diagram showing the symmetry of the unit cell viewed along the b -axis is given by Taylor, *op. cit.*, p. 428. One showing the symmetry looking along the c -axis appears on p. 100 of vol. 1 of the *Internationale Tabellen zur Bestimmung von Kristallstrukturen*, 1935 (symbols used are explained on pp. 92-93.)

⁹ Of course it must be realized that the exact atomic parameters of sanidine are not known. As Taylor says (*op. cit.*, pp. 431 et seq.); "the real symmetry of sanidine cannot be monoclinic holohedry; for the $\text{Al}:\text{Si}$ ratio is always 1:3, so that the 16 ($\text{Al}+\text{Si}$) atoms which in this structure are divided into two groups of 8 Si_1 and 8 Si_2 without attempting to distinguish Si from Al , must really be divided into four groups of which three contain 4 Si each and one contains 4 Al ." The evidence however favors lower monoclinic symmetry, rather than triclinic. Taken as monoclinic holohedral, sanidine is what Barth and Posnjak (*Jour. Wash. Acad. Sci.*, Vol. 21, p. 257, 1931) have called a variate atom equipoint structure (also see Barth, *Am. Jour. Sci.*, 27, 282, 1934), and what Strock (*Zeit. Krist.*, Vol. 93, pp. 285-311, 1936) would classify as I. B. 2, a shared monocoordinate complete lattice defect structure.

¹⁰ In some models it may be desirable to add a few fine wires to outline the edges of a polyhedron, the coigns of which mark the centers of a single kind of atom.

student with but slight technical ability can complete the job. Moreover, such a problem serves as an ideal introduction for students to the beauties and intricacies of the patterns on which crystals form. Some models of high symmetry such as the diamond are more difficult to make, since a superior quality of workmanship is needed to avoid mechanical distortion. In actual practice the silicon and oxygen positions are not in general completed before the other positions, and in no cases have plastic wood balls been added for part of the ions before the structure network was finished. The scheme followed in building the sanidine model was not one of expediency, but rather one to best illustrate exposition of the method.

In building models such as muscovite¹¹ with its sheets consisting of double layers of SiO_4^{-4} -tetrahedra (and possibly in making representa-

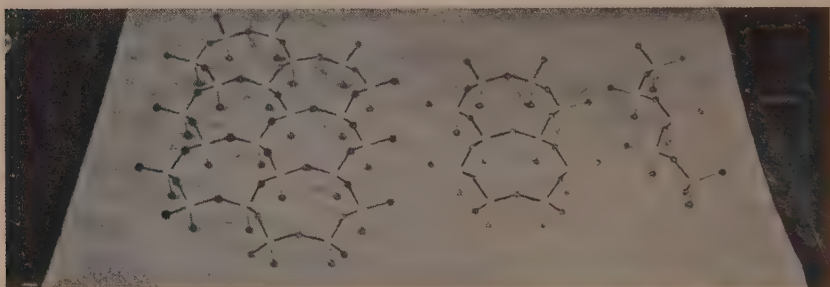


FIG. 4. SiO_4^{-4} -tetrahedra combined into a layer (left) forming one-half of a sheet, a band (or double chain), and a (single) chain (right), as seen in micas, amphiboles, and pyroxenes. The Si^{+4} -ions appear white; the bonds *within the structure*, black.

tions of band and chain structures as amphiboles and pyroxenes), it is time-saving to modify the method of model building as described for sanidine as follows. Lay out on a plan similar to Fig. 1 regular hexagons with sides 7.2 cms. long (where 2.4 cms. is equivalent to 1 Å.); the apices of these mark the positions of Si^{+4} -ions. Continue the pattern so that the hexagons fill "plane space." At the middle points of the hexagon sides mark the locations of O^{-2} -ions. Insert pegs extending 5.2 cms. above the baseboard in holes bored at these middle points; no holes need be made at the hexagon corners. Prepare rods like those described that were used in making the SiO_4^{-4} -tetrahedron framework of sanidine; i.e., 7.78+ cms. long bent in the middle at an angle of $109\frac{1}{2}^\circ$. Holding an end of one of these bent rods at a hexagon corner, with the portion of the rod held

¹¹ Jackson, W. W. and West, J., The crystal structure of muscovite: *Zeit. Krist.*, Vol. 76, pp. 211 et seq, 1930. References to papers through 1934 describing crystal structures are given by Wyckoff, R. W. G., *The Structure of Crystals*, 1931, and *Supplement*, 1935.

being in a vertical position, rotate it till the other end of the rod touches the top of an oxygen peg and, after fluxing, solder this junction. Hold another bent rod under the rod just fastened down so that the two bends "hook" together, and solder at this point (position of a Si^{+4} -ion) while the two ends of the loose bent rod rest on the tops of two oxygen pegs at the middles of the hexagon sides. This completes one SiO_4^{-4} -tetrahedron of the layer, and continuance of this procedure results in the layer, or a band, or just a chain. Adding plastic wood balls and painting give the results shown in Fig. 4.

APPENDIX

The senior author has devoted some thought to coloring schemes. For simplicity the axial directions as shown by the outlines of the unit cell are painted red, white, and blue for a , b , and c , respectively. This may appeal to foreigners rather less than to our own American students. All O-Si-O bonds that form parts of framework, sheet, band, or chain structures are painted yellow; otherwise they are colored orange or, if the number of types of bonds is small so that these can all be differentiated by varying sizes of wire, left uncolored.

TABLE 1. COLORS USED FOR DESIGNATING VARIOUS ELEMENTS

Color	*Radius (Å)	Elements
Pink	1.5 -2.2	(S, Se, Te) ⁻² , (Cl, Br, I) ⁻¹ , (F, OH ^{**}) ⁻¹ , Sb, Pb
Red	1.32	O ⁻²
Brown	1.3 -1.5	(Ba, Pb) ⁺² , K ⁺¹ , (NH ₄) ⁺¹ , Te, Ta
Orange	1.2 -1.3	La ⁺³ , Sr ⁺² , Fe
Lemon chrome	.98-1.05	Na ⁺¹ , S
Ivory yellow	0.9 -1.2	Ce ⁺⁴ , (Yt, Rare Earths) ⁺³ , (Ca, Mn) ⁺² , Se
Light green	0.8 -0.9	Zr ⁺⁴ , Sb ⁺³ , (Fe, Co) ⁺²
Dark green	0.7 -0.8	Mn ⁺³ , Mg ⁺² , Li ⁺¹
Light blue	0.6 -0.7	Mo ^{+6,4} , Sb ⁺⁵ , Cb ^{+5,4} , W ⁺⁴ , (Ti, V) ^{+4,3} , Fe ⁺³
Dark blue	0.4 -0.6	Mn ^{+7,4} , V ⁺⁵
Lilac	0.2 -0.4	S ⁺⁶ , (N, P) ⁺⁵ , B ⁺³ , Be ⁺²
White	0.39	Si ⁺⁴
Gray	0.47-1.35	As ^{+5,3} , As
Black	0.15-0.77	C ⁺⁴ , C
Aluminum	0.4 -1.13	Cr ^{+6,3} , Sn ⁺⁴ , Al ⁺³ , (Ni, Zn, Cd, Hg) ⁺² , Ag ⁺¹
Aluminum	1.3 -1.53	Pd, Ag, Sn, Os, Ir, Pt, Hg
Copper	0.7-1.24	Cu ⁺² , Cu ⁺¹ , Cu
Brass	1.37-1.40	Au ⁺¹ , Au
Bronze	1.17-1.77	Bi ⁺³ , Bi

* As given in *Internationale Tabellen zur Bestimmung von Kristallstrukturen*, vol. 2, pp. 611-614, 1935. Goldschmidt values used where available. C. N. 8 for atoms (except C).

** The radii of the F⁻¹- and OH⁻¹-ions are probably about 1.33 and 1.4 Å, respectively, but they are arbitrarily put with the "pink group" as it is desirable to include them with the electronegative ions, and yet they should be distinguished from O⁻².

There is no obvious systematic scheme of coloring the balls to represent the various elements which is likely to meet with general agreement. It is impractical and unnecessary to have 92 shades; moreover in case a single element occurs as ions of different valencies in a given mineral, as for example in the case of iron in silicates, it is necessary to differentiate between these. It is, however, obviously desirable that some uniform system be adopted.

Since it is probably not practicable to have balls of plastic wood of pronouncedly different sizes,¹² the attempt has been made to have color serve the double purpose of designating the element and giving some picture of its size, though actually a better size conception comes from the dimensions of the opening in which a given ball is centered. By making declining ionic or atomic radius go hand in hand with decreasing wave length, color is made to serve this double purpose, as is brought out in Table 1. The radii limits shown in this table may be taken as standard for 6-6 or 6-4 coordination at ordinary temperatures, but vary by plus 3 to minus 6-8 per cent for other coordinations. It is less practicable to use atomic radii as a basis for color separation in the thickly populated range from 1.2 to 1.5 Å. (orange and brown, Table 1). Aluminum paint is therefore substituted for silver-colored elements which occur as minerals, or which (as Cr, Ni, Zn, Cd) are in everyday use for plating, as well as for Al^{+3} . For the chromatic colors there is a close correspondence between size and wave length, although red is reserved for the all important O^{-2} , while yellow (lemon chrome) calls to mind the sodium flame, as well as elementary sulphur.

¹² Wyckoff (*op. cit.*) in his drawings has used circles ("balls") which are in general too small for packing models but yet show great size differences. It is not practicable to make analogous models using plastic wood balls. Gruner (*op. cit.*) "makes each element a different size." He does not state the size variations, but at best it probably gives but a faint picture of actual size differences.

MINERALS AND ASSOCIATED ROCKS AT COPPER MINE HILL, RHODE ISLAND

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ABSTRACT

Copper Mine Hill, Rhode Island, consists of a series of green schists with beds of quartzite and limestone which have been intruded by riebeckite granite. At and near the contact of the granite are mineral deposits of the contact metamorphic type which were once worked for copper. These deposits are described, as are veins of several types.

LOCATION AND HISTORY

Copper Mine Hill is located in the town of Cumberland which is in the northeast corner of Rhode Island (Plate I). This town has long been known for the great variety of its minerals and is said to have been named for Cumberland, England, because of its minerals and mines. Among the mining and quarrying ventures are the old coal mines at Valley Falls, metal mines at Copper Mine Hill and elsewhere, old iron mines and the present "trap rock" quarry at Iron Mine Hill, granite quarries at several places, the quarry for quartz at Diamond Hill, and a few small limestone pits. Jackson¹ states that over fifty prospect pits or mines were found on Copper Mine Hill alone, and suggested that some of them were dug on the assumption that the chalcopyrite was gold. We did not find fifty holes, but no doubt many were small and some have been filled.

We have been unable to learn much about the history of the mines at Copper Mine Hill, although we searched through most of the published histories and interviewed members of old families in the region in the hope that they might have old records of the mining. Jackson's report in 1840 refers to the mines as "ancient mine holes."² Robinson's *Catalogue of American Minerals* issued in 1825 states that the mining was done forty to a hundred years previously,³ while an article by the same author written in 1824 states that the mining was done forty to forty-five years prior to that date.⁴ We have thus far been unable to go further into the history of these mines.

It has been stated in the earlier writings that the shaft at the main mine was from 70 to 100 feet deep and that there was a tunnel 250 feet

¹ Jackson, Charles T., Report on the geological and agricultural survey of the State of Rhode Island, p. 55, 1840.

² *Op. cit.*, p. 55.

³ Robinson, Samuel, *A Catalogue of American Minerals*, p. 84, 1825.

⁴ Robinson, Samuel, Notice of miscellaneous localities of minerals: *Am. Jour. Sci.*, 1st series, vol. 8, pp. 230-232, 1824.

long. It is not possible to enter the old workings now, but the dumps afford some opportunity to study the type of ore. The north wall at the opening of the main mine exposes some of the geological relationships, which may be seen also at some of the smaller pits.

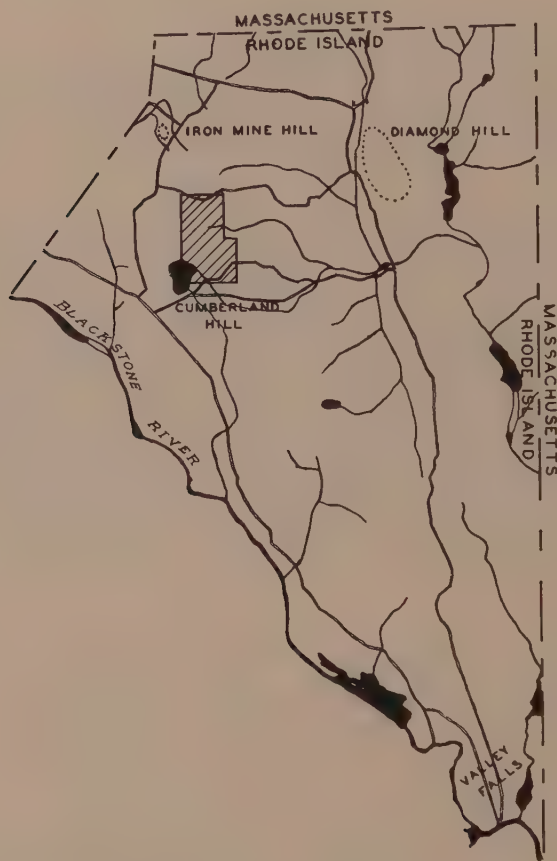


PLATE I. Map of Cumberland, Rhode Island, showing location of area described in this paper. Not all of the roads are shown.
(Approximate scale, two miles to the inch.)

There are several recent cuts on the west slope of the hill, where some of the minerals may be seen in place. Quarry 2 (Plate II), especially, shows some of the garnet rock in place and furnishes the only good specimens of the quartz-epidote-adularia veins. These recent quarrying operations have been for the purpose of obtaining uniform green schist and have, therefore, avoided most of the interesting mineralogical phases.



PLATE II. Geological Map of Part of Copper Mine Hill, Rhode Island.

MAP

A portion of the topographic map of the Providence Quadrangle of the United States Geological Survey was used as a base for geological mapping, but the lack of detail on this map and the dense covering of brush over a part of the area made mapping rather difficult. These difficulties were largely overcome by W. R. Benford of the Department of Engineering of Brown University who made a traverse by transit and stadia across the area. We hereby express our sincere thanks to Mr. Benford for this assistance.

PREVIOUS WORK

No published paper has been primarily concerned with these ore deposits. The minerals were listed by Robinson in 1824 and 1825, and Jackson described the minerals in 1840.⁵ Emerson and Perry⁶ described these deposits briefly in their report on the granites and green schists of Rhode Island. Warren and Powers' paper in 1914 covered this area, but they paid little attention to the ores.⁷ Fisher and Gedney⁸ listed some of the minerals in 1926.

SCHIST

The oldest rocks in this area are green and gray colored schists with associated limestone and quartzite. This series is included in the Ashton schist of Warren and Powers,⁹ and in the Marlboro formation of Emerson and Perry.¹⁰ It is believed to be of Algonkian age.

The schists of Copper Mine Hill are fine-grained. The color varies from gray to green, to almost black. In places the rock has a slaty structure. Such rock is generally rather light in color. Certain of the darker phases are massive in structure. Nodules, veins, and streaks of epidote abound, especially in the massive portions. The main minerals in the body of the rock, as determined mainly from thin section, are actinolite, epidote, chlorite, and quartz. There are also many aggregates of a fine textured material that are probably of a sericitic nature. Biotite is common, but generally is not a main constituent. Magnetite is abundant in small grains and pyrite is present sparingly.

⁵ Jackson, *op. cit.*

Robinson, *op. cit.*

⁶ Emerson, B. K., and Perry, J. H., The green schists and associated granites and porphyries of Rhode Island: *U. S. Geol. Survey, Bull.* 311, pp. 13-15, 1907.

⁷ Warren, C. H., and Powers, Sidney, Geology of the Diamond Hill-Cumberland District in Rhode Island-Massachusetts: *Bull. Geol. Soc. Am.*, vol. 25, pp. 435-476, 1914.

⁸ Fisher, Lloyd W., and Gedney, Edwin K., Notes on the mineral localities of Rhode Island. I. Providence County: *Am. Mineral.*, vol. 11, p. 336, 1926.

⁹ Warren and Powers, *op. cit.*

¹⁰ Emerson and Perry, *op. cit.*, pp. 13-15.

QUARTZITE AND LIMESTONE

Associated with the schist are several small beds of quartzite and limestone. The quartzite occurs in small lenses, 25 to 50 feet long and 10 to 20 feet thick. It is white to light gray in color and is rather sugary in texture.

Beds and small lenses of limestone are present in the schist at several places. Evidence of limestone is found at most of the ore bodies, but generally replacement has been so complete that not much limestone remains. The long bed 200 feet southeast of Quarry No. 2 has not been greatly affected by mineralizing solutions. It is a white, crystalline, somewhat dolomitic limestone with numerous crystals of tremolite. Along the contact of this limestone bed with the schist are alternating bands of brown garnet and actinolite. Most of the limestone contains some talc and a serpentinous mineral which resembles the "bowenite" of other limestone bodies in Rhode Island. According to Selfridge this should be called antigorite¹¹ Much of this bed has been removed, presumably for lime.

The beds of quartzite and limestone are parallel to the schistosity of the green schist. On the north wall of the excavation, at the main shaft, the limestone has the appearance of being at the crest of a tightly compressed anticline. Elsewhere there are small disconnected lenses of limestone which probably represent fragments of a broken and sheared bed.

There is considerable uncertainty about the origin of the green schists of Rhode Island, some of which are considered to have been sedimentary and some igneous. The intimate association of the schist with limestone and quartzite suggests that the whole series at Copper Mine Hill was sedimentary.

GRANITE

Intruding the schist series of Copper Mine Hill is a riebeckite granite which is probably related to the Quincy granite of Devonian or early Carboniferous age. It is medium to fine-grained and is in places somewhat porphyritic. The color is light gray to gray. There is some tendency toward a banded structure. Megascopically, the rock is composed of light gray to bluish feldspar, areas of sugary quartz, black amphibole and pyroxene, and small amounts of biotite. Here and there may be seen patches of bright purple fluorite. Thin sections reveal that the main minerals are micropertite in large grains, areas of fine-grained quartz, riebeckite, and aegirite. Some thin sections have considerable biotite. Minor constituents are astrophyllite, purple fluorite, magnetite, musco-

¹¹ Selfridge, George C., Jr., An x-ray and optical investigation of the serpentine minerals: *Am. Mineral.*, vol. 21, pp. 500-501, 1936.

vite, and concentric grains of what Warren and Powers called a leucoxenic alteration.¹²

There is some irregularity in the shape of the granite intrusions, but they are mainly along the schistosity of the schist, and the granite appears to be in sills dipping to the northeast.

Gash Veins in Granite

The granite is cut by numerous gash veins and lenses of quartz up to a foot in width. This type of vein is almost entirely confined to the granite. Many of the veins contain nothing but quartz, but purple fluorite, ilmenite, and a very few poor crystals of dark green beryl have been found.

TOURMALINE VEINS

There are a very few small veins of black tourmaline. One occurs in the schist about 200 feet north of the main mine. It is about one inch wide, cuts through almost at right angles to the schistosity, and is composed almost entirely of minute crystals of black tourmaline. Some quartz accompanies the tourmaline. Another such vein was found cutting the granite.

MINERAL AND ORE DEPOSITS

Relationships

The broader relationships of the ore bodies are revealed in part, but exposures are not of the kind to show many of the details. At all of the ore bodies there are indications that the ores are related to limestone, the evidence being partially replaced blocks of limestone on the dumps, and beds of limestone exposed in the mine workings. There is also evidence to show that the ores are related to the granite intrusions. At Prospects 1 and 2, the ores are at the granite contact. Prospects 3 and 4 are over 400 feet from any outcrop of granite, however. They may be related to an unknown granite intrusion in the schist beneath, or their location may have been determined by a permeable zone in the schist. The limestone beds associated with these prospects may have been such a permeable zone. The ores of the main mine are not very near any large body of granite. There is a small sill to the southwest, near Sneece Pond, and it probably cuts under the main mine. With sills of granite so common here it is very likely that all these ores are near some granite intrusion, and the general relationships suggest that the deposits are of the contact metamorphic type. This is further indicated by the minerals to be described later in this paper.

¹² Warren and Powers, *op. cit.*, p. 465.

Most of the study of the minerals of the ore deposits was made on specimens from the dumps of the old prospect pits and mines. Several of the minerals are in place at Quarry 2, however. The opaque minerals were studied by reflected light and the others were identified with the petrographic microscope.

Tremolite

The limestone usually has tremolite, whether associated with ore deposits or not, and much of it must have originated in the dynamic metamorphism which affected the rocks before the formation of the ores. Some may have originated as a result of the contact metamorphism by the riebeckite granite, however. In the limestone the tremolite is in small needles up to a quarter of an inch long. At the dump of the main mine are large pieces of a magnetite-tremolite rock. The tremolite is present in large streaks through the magnetite and as individual crystals scattered through it. The needles are arranged in parallel fashion. The color is a faint green and the optical properties indicate that it is a tremolite near actinolite in composition.

Epidote

Epidote is one of the most widespread minerals at Copper Mine Hill. It occurs in the body of the schist and as nodules and veins in the schist, in places which seem not to have been affected by contact metamorphism. It also occurs in the contact metamorphic deposits and in quartz-epidote, calcite-epidote, actinolite-epidote-calcite, and quartz-epidote-adularia veins. The epidote has about the same optical properties in all these occurrences. The intermediate index of refraction is near 1.76, the optic angle large, and the optic sign negative. It seems to be an iron-rich variety.

Actinolite

Actinolite is present as one of the minerals of the schist, as an important mineral of the contact metamorphic rock, and in veins. The veins include actinolite, actinolite-quartz, and actinolite-epidote-calcite veins. It is all dark green in color. In some of the veins the fibres are rather long and good specimens may be obtained.

Pyroxene

At Quarry No. 2 may be found quarter-inch crystals with octagonal cross-section. They have been altered to amphibole with optical properties near those of actinolite and must, therefore, be examples of uralitiza-

tion. The crystals were originally embedded in calcite, but in places the calcite has dissolved, leaving the crystals projecting into cavities.

Diopside

At Prospects Nos. 1 and 3 white diopside occurs in radial groups with the individual crystals up to an inch in length. The optical properties of this mineral indicate that it is near pure diopside. It was not found at any of the other localities.

Hornblende

Brilliant black crystals of hornblende occur with calcite in veins at Prospect No. 3, and with epidote in veins at several other places. The intermediate index of refraction is near 1.65, the optic angle is moderately large, the optic sign is negative, and the maximum extinction angle in the vertical zone is about 25°.

Garnet

Garnet is one of the most abundant minerals in the contact rocks. It usually forms a massive rock and shows crystal faces only when found in cavities, which seem to have been formed by the solution of calcite. The garnet is mainly light brown, although the color varies somewhat, even in single crystals. The crystals are usually lighter in the interior. The interior portions may have a distinct greenish cast. The darkest garnet is dark reddish brown and occurs in veinlets. The index of refraction is higher than 1.77. Chemical tests indicate it to be andradite, with the lighter colored parts varying toward grossularite. The darker garnets contain more iron.

Chlorite

Chlorite is one of the main constituents of the green schist. It also occurs in the limestone at the main mine, where it seems to have been formed by contact metamorphism. Flakes up to 1½ inches across are arranged in a zone in the limestone near the contact with the schist. The mineral is light green and has a pearly luster. The index of refraction on cleavage flakes is about 1.575, but is variable. The optic angle is small and the optic sign is negative. These properties indicate penninite.

Quartz

Quartz is an important constituent of the green schist, it is present in the veins associated with the granite, and it occurs in many other types of veins, but it is not abundant in the contact rocks and there is very little silicification of the older rocks.

Magnetite

Magnetite is a very abundant and widespread mineral in the contact zone. Magnetite rock is found in large masses on the dumps, especially at the main mine. It is associated with almost all the minerals here, but especially notable are the masses of magnetite-tremolite rock and the magnetite-chlorite rock. It is fine-grained and massive.

Molybdenite

At the main mine dump, molybdenite was found associated with crystals of magnetite in fragments of greenstone. Many pieces of the old chalcopyrite ore contain flakes of molybdenite. It is also associated with garnet at Quarry No. 2. It seems to be later than magnetite and earlier than chalcopyrite.

Pyrite

Pyrite is not an abundant constituent of the ores, but is rather widespread in occurrence. Some is massive and some shows crystal faces. In the ores it is later than magnetite and earlier than chalcopyrite.

Chalcopyrite

Chalcopyrite is so scarce at the main dumps that one wonders why this was ever called a copper mine, but on a rock surface near the main shaft is an accumulation of rusty, two-inch pieces of ore which contain considerable altered chalcopyrite and some molybdenite. These pieces are probably all that remain of the casks of ore which Jackson said were present in 1840.¹³ Small amounts of the chalcopyrite may be found at the other prospects, but it is usually much altered and is not very abundant. It is also found in calcite-epidote veins in the schist at Quarry No. 1.

Bornite

Bornite was found in irregular veins at Quarry No. 2. It was also found at Prospect No. 2. It is not entirely clear whether this mineral is primary or secondary.

Sphalerite

One specimen from a bornite vein at Quarry No. 2 contained considerable dark sphalerite.

¹³ Jackson, *op. cit.*, pp. 55-56.

Knebelite

Jackson describes a forty-foot bed of a "remarkable ore of manganese" and states that the ore mineral is knebelite.¹⁴ Emerson and Perry quote Jackson's description, but give no indication that they ever saw the bed. We were unable to find such a bed "near the pond." A short distance southeast of the southeast corner of our map is a small deposit of manganese oxides, however.

QUARTZ-EPIDOTE-ADULARIA VEINS

At Quarry No. 2 are several quartz-epidote-adularia veins from one inch to several inches wide cutting approximately at right angles to the schistosity. The epidote is bright pistachio green in color and was probably the first mineral formed, although it was in part contemporaneous with the quartz. The quartz forms crystals which project into the center of the veins. Adularia, which is the latest mineral in the veins, forms crystals up to $1\frac{1}{2}$ inches across. It is flesh-colored and opaque on the outside, but rather glassy inside. Probably these veins represent a later lower-temperature mineralization. Other evidence for a later mineralization of lower temperature are the small veins west of Sneece Pond which contain galena, sphalerite, chalcopyrite, smoky quartz, white fluorite, and bright purple fluorite.

SECONDARY MINERALS

In the tremolite-magnetite rock, and in the garnet-magnetite rock, antigorite occurs as an alteration of tremolite, probably the result of hydrothermal action.

Polished sections of the opaque minerals reveal minute veinlets of covellite replacing bornite. Small amounts of chalcocite were found with the bornite and covellite. Textural relationships do not indicate whether the bornite is primary or secondary.

A thin coating of botryoidal, white opal was observed on a few joint planes and lining small cavities in the garnet rock at Quarry No. 2. A fragment of the ore from the dump at the main mine contains opal filling the spaces between the fragments of a piece of brecciated chalcopyrite.

The characteristic weathering products, limonite, malachite, and azurite were seen at many places in the area.

SUMMARY AND GEOLOGIC HISTORY

This area was at one time composed of a series of rocks which were metamorphosed to green schists, quartzite, and crystalline limestone.

¹⁴ Jackson, *op. cit.*, p. 54.

The minerals of the green schists are the result of this metamorphism, as probably is some of the tremolite, serpentine, and talc in the limestone. These rocks are considered to be of pre-Cambrian, probably Algonkian, age.

In Devonian or early Carboniferous time the green schist series was intruded by sills of granite, and contact metamorphic deposits were formed. The silicate, oxide, and sulphide minerals formed are characteristic of high-temperature contact-metamorphic deposits. In general, the silicates were formed first, the oxides next, and the sulphides last. Probably several types of veins containing quartz, beryl, tourmaline, fluorite, and ilmenite were formed at about this time.

Veins of low temperature types, such as the quartz-epidote-adularia veins, were formed somewhat later. Common weathering products were formed still later, probably in post-glacial time. The number of minerals found here is about forty.

PARAGENESIS OF THE MINERALS FROM BLUEBERRY MOUNTAIN, WOBURN, MASSACHUSETTS

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INTRODUCTION

Blueberry Mountain (300 feet) lies 9 miles N.N.W. of Boston, $3\frac{1}{2}$ miles north of the limits of the Boston Basin, in the southeast part of Woburn near the Winchester boundary line. It is one of numerous hills of about the same height which form the main relief of the Boston quadrangle.

In 1913 a small quarry was opened about 400 feet northeast of the present operations by the Winchester Rock and Brick Company. The life of this development was short, ending in 1919 when the project was taken over by the General Sand and Gravel Company of Easton, Pennsylvania. Due to more efficient management and greater financial resources, this company extended its operations to the site of the present quarry. The abandonment of the old quarry was caused by trouble with rock breaking along the joint system. The dip and strike of the joint system is such that in blasting, great overhanging ledges resulted under which it was dangerous for the men to work. When worked from the southern side of the hill this difficulty was overcome.¹ Up to the present time over 4,000,000 tons of rock and 500,000 tons of overburden have been removed, and as yet only a small part of the hill has been quarried.

GEOLOGIC HISTORY

The principal rock of the quarry is the pre-Carboniferous granodiorite which is younger than the Waltham gneiss over which it is thrust, younger than the gabbrodiorite into which it is intruded, and probably older than the granite which lies a little to the north. Into all these rocks aplite and pegmatite dikes have been intruded.

The igneous rocks may have been derived from a magma which intruded the pre-Cambrian Waltham gneiss, incorporated some of the wall-rock and differentiated in place, producing in turn the Salem granodiorite, the Wakefield granite, and dikes of aplite and pegmatite. Later intrusive activity resulted in dikes in the granodiorite and lit-par-lit injections in the gneiss. Still later hydrothermal activity produced a complicated series of minerals.

After the formation of the pegmatites and the subsequent hydrothermal activity, thrust faulting forced the Salem granodiorite over the

¹ Miller, Robert B., Pegmatites of Blueberry Mountain, Winchester Highlands, Massachusetts (unpublished).

Waltham gneiss, which is exposed on the east side of the quarry. The main thrust faults are associated with smaller thrusts and normal faults. The sub-parallel arrangement and lens-shape of the pegmatites indicate that these bodies were injected along planes of weakness. Their sharp contacts with the granodiorite and gneiss show that they were not formed in place. During or after these movements a complicated system of small veins traversed the pegmatites, granodiorite and gneiss indiscriminately. These veins may have been produced by torsional stresses; renewed hydrothermal activity caused them to be mineralized.

PARAGENESIS

The mineralogical sequence is divided into three main stages—magmatic, pegmatitic, and hydrothermal. The hydrothermal phase is subdivided into three stages of falling temperatures and a zeolite phase.

The writer wishes to introduce at this time a new term, which he believes will fill a need long felt. There are certain minerals that form under conditions nearly similar to those which produce the zeolites; for these minerals the writer proposes the term "anchi-zeolite," meaning "near zeolite." Under this term will be included such minerals as prehnite, datolite, babingtonite, and other minerals formed under similar conditions.

The minerals of the several phases occur in three different types of deposits. The magmatic minerals are found in the granodiorite. The pegmatitic and the high- and medium-temperature hydrothermal minerals are found in the pegmatites themselves, which are intrusive into the granodiorite. The anchi-zeolites are confined to small veins cutting the granodiorite and pegmatite dikes. The zeolite minerals and prehnite are found chiefly in small veins that traverse the gneiss; but to a limited extent they are found in veins in the granodiorite and pegmatite.

The minerals of the magmatic stage are quartz, orthoclase, andesine, hornblende, magnetite, apatite, and sphene. Sericite, which is abundant in the granodiorite, is an alteration product of feldspar. The remaining minerals to be described are listed and arranged in the paragenetic table under their appropriate headings.

In the table, the association of the various minerals may be seen. It will be noted that there is considerable repetition of minerals in the various phases; under the section on descriptive mineralogy repeated occurrences of such minerals will be described under one title.

DESCRIPTIVE MINERALOGY

A detailed description of every mineral found at the Blueberry Mountain quarry will not be given. The common minerals, with which every-

one is familiar, need simply a general statement as to occurrence. The minerals requiring fuller description are babingtonite, prehnite, albite, orangite, thorite, and allanite. The list of minerals follows the order in the paragenetic table with some modification due to repetition in the table.

Granodiorite. The mineral composition of the granodiorite is approximately as follows:

Hornblende.....	47%
Andesine.....	35
Orthoclase.....	5
Magnetite.....	5
Quartz.....	5
Apatite.....	} 3
Sphene.....	
Sericite (Alteration of the feldspars)	

The granodiorite shows strong alteration by hot hydrothermal solutions, resulting in the almost complete sericitization of the feldspars. The hornblende was derived from an original augite. Near vein and pegmatite contacts the hornblende is altered to babingtonite, the alteration starting in cleavages and occasionally replacing practically the whole crystal. Magnetite is accompanied by ilmenite; both are alterations of the original augite, the ilmenite being occasionally altered to leucoxene. The quartz is badly strained, reflecting the effects of earth movements.

Microcline and Orthoclase. These minerals occur as large crystals of pink color growing from the walls of the pegmatite dikes. The coloration is much more intense near the haloes and radiating cracks of radioactive minerals. They vary in size from relatively small crystals to some which are about a foot in diameter. Carlsbad twins attached to the walls at one end of the *c*-axis are common. The great majority of the crystals are, however, untwinned.

Biotite. This mineral probably occurred in medium-sized, plate-like crystals which are now completely altered to chlorite.

Hornblende. Masses of this mineral are sparsely scattered through the pegmatite. Though not in well-defined crystals, they exhibit typical amphibole cleavage. Implanted on the walls of small cross-cutting veins and cavities occur needle-like, pale blue-green crystals of an amphibole, probably tremolite.

Quartz. In the pegmatites themselves this mineral followed the crystallization of the feldspars, filling in the available space between the feldspar crystals. It is milky white in color. A second generation can be seen lining cavities in brilliant, small transparent crystals.

Magnetite. Rather small patches of magnetite occur in the pegmatite

near the contact, and on the borders of xenoliths of granodiorite in the pegmatite. Small crystals, octahedron modified by dodecahedron, are also found in the secondary vein-cavities.

Sphene. This mineral occurs as large chocolate-brown masses with well-developed partings. It replaces feldspar and is itself replaced by chlorite. It is also found in small, highly lustrous crystals in the cavities.

Allanite. This radioactive mineral occurs rather abundantly in quartz and feldspar, in crystals ranging from 5 centimeters in length down to 3 millimeters. The matrix surrounding the crystals, whether of quartz or feldspar, shows radiating fractures which seem to have been caused by radioactivity. Unaltered, the mineral is black and vitreous; but when alteration has taken place it is dull grayish-black.

In powdered form under the microscope the mineral appears light olive-green with no cleavage. Some of the grains are isotropic; others are slightly birefringent; and still others show patches of gray interference colors. The grains are cut by minute veins of a mineral which has bright interference colors and a much higher index of refraction than the principal portion of the grains. These small veins may consist of epidote.

The index of refraction of the greater part of the allanite varies from 1.698–1.715. The grains which have the gray interference colors have an index greater than 1.71; the isotropic grains have a lower index. The birefracting material has an index between the two.

As far as can be determined microscopically the isotropic material appears to be an alteration product of the anisotropic allanite. This agrees with Goldschmidt's hypothesis² of the "metamict condition," the isotropic material being an alteration product of the original crystalline anisotropic allanite.

At Woburn the megascopic crystals of allanite show rude prismatic forms suggesting an anisotropic mineral with an alteration rim surrounding the fresh material. It would seem probable, therefore, that the alteration proceeded from the anisotropic allanite to the isotropic alteration product.³

Orangite, Thorite. These rare radioactive minerals occur scattered throughout the pegmatite in very small crystals. The tetragonal crystals, which are rarely a centimeter in length, have the first-order pyramid and the second-order prism. Like allanite they produce radial cracks in the matrix. The pure orangite is of a bright orange-yellow color, transparent and glassy.

² Goldschmidt, V. M., *Geochemische Verteilungsgesetze der Elemente*, III, pp. 51–58, 1924.

³ Tunell, George, The paragenesis of the pegmatite minerals of Winchester, Massachusetts, 1925, (unpublished).

When powdered and observed under the microscope, the seemingly pure orangite was found to be made up of the following:

1. Isotropic fragments, colorless, with an index less than 1.70.
2. Cloudy and threaded patches in the first, colorless, faintly birefringent.
3. Isotropic, yellow, non-pleochroic, with index slightly greater than 1.70.
4. Black opaque flakes.
5. Zircon fragments, some of which are altered to cyrtolite.⁴

It is evident that the orangite at Woburn is not a pure mineral but a mixture. Originally orangite most likely formed with zirconium replacing a portion of the thorium. The black opaque flakes may consist of a sulphide which has been introduced at a later time. The pure orangite is represented by the yellow isotropic grains which have an index greater than 1.70.

It appears probable that orangite containing some zirconium formed under certain definite conditions; that under these conditions the mineral is perfectly homogeneous and stable; that when the equilibrium conditions changed the mineral became unstable and formed zircon and orangite; that with alteration by hydrothermal solutions some of the remaining orangite altered to thorite, the thorite to an undetermined substance, and the zircon to cyrtolite.

Epidote. This mineral is especially abundant throughout the quarry. It occurs in two generations, the first in pegmatite, where it forms crystallized masses of dark green color, often a foot in diameter. The crystals usually radiate from a center, appearing to replace feldspar at times and again crystallizing on the faces of the feldspar. The great abundance of this mineral warrants the use of the term "unakite pegmatite" for the pegmatites of this quarry. The epidote has the following composition as determined by its optical properties: $\beta = 1.752$

27% (H Ca₂ Fe₃ Si₃ O₁₃)

73% (H Ca₂ Al₃ Si₃ O₁₃)

It contains 12% Fe₂O₃. A second generation is found in small veins and cavities that traverse the pegmatites and the granodiorite. Here the epidote is in fine clear transparent crystals of light yellow-green color. The crystals are particularly well developed in simple combination. As far as could be determined the composition of the second generation of epidote is the same as the first.

Albite (variety cleavelandite). Fine white cleavage fragments of this mineral, with prominent albite twinning, occur as an alteration product of orthoclase and microcline. A second generation of albite consists of small transparent crystals attached to the walls of small veins. These

⁴ Noble, James A., The pegmatites of the Winchester Highlands Quarry, Blueberry Mountain, Woburn (unpublished).

crystals are elongated parallel to $[100]$ and are sometimes twinned (Fig. 1).

Tourmaline. One small, irregularly crystallized mass of this mineral was found. It is black in color but under the microscope shows a deep dirty green pleochroism. It is replaced by albite of the high-temperature

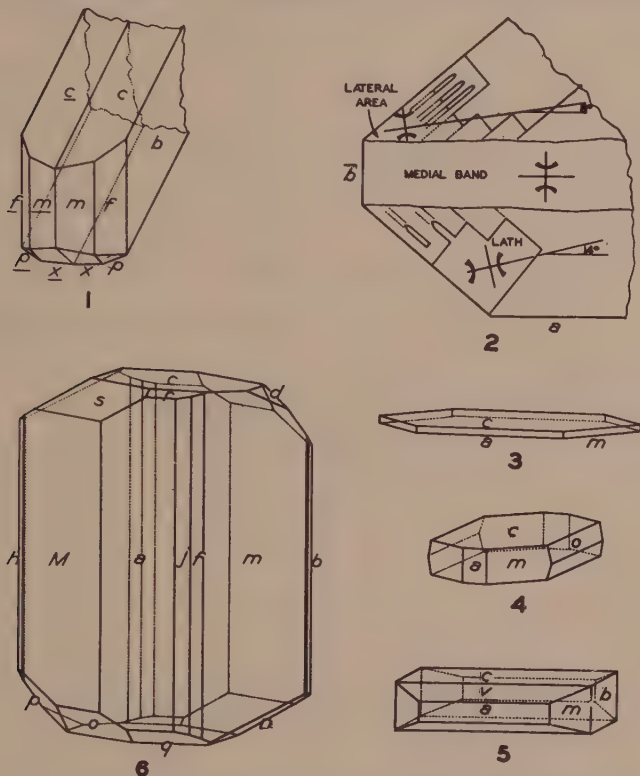


FIG. 1. Albite; typical crystal twinned on (010) and elongated $[100]$.

FIG. 2. Prehnite; fragment of a crystal showing hourglass structure and the optical orientation in several segments. After unpublished notes by G. Tunell.

FIGS. 3-5. Prehnite; typical habits.

FIG. 6. Babingtonite; typical doubly terminated crystal.

hydrothermal phase, but the relationship to the other minerals of this phase could not be ascertained.

Chlorite. This mineral is found as an alteration product of biotite and epidote. In the latter mineral it sometimes completely replaces the epidote. The appearance is most striking when it forms solid masses, several inches across, of green to blackish green color and dense, scaly texture. It is seen as an alteration product of sphene. Another generation forms

in small veins and cavities, as minute six-sided crystals of a deep blue-green color. The chemical character of these chlorites was not determined.

Pyrite. Large ill-defined crystallized masses occur in the pegmatite. It varies in color from silver-white to light yellow. A second generation of pyrite forms beautifully crystallized individuals in which rare forms are to be seen. Besides the cube and octahedron, there are developed the dodecahedron, a diploid, and a trapezohedron.

Molybdenite. One small crystallized mass has been found as a pegmatite mineral.

Adularia. This mineral is found in the small veins and cavities lining the walls in small, brilliant, transparent crystals.

Chalcopyrite. Small crystals of this mineral are found growing on the second generation pyrite.

Garnet (andradite). This mineral occurs in poorly crystallized individuals of a wine-red color.

Calcite. There appear to have been three generations of this mineral characterized by:

1. Flat rhombohedrons with very subordinate base and prism.
2. Negative unit rhombohedrons with very subordinate base.
3. A deposit of a thin crust on the crystals exhibiting the negative unit rhombohedron.

It should be noted that the small veins are filled with calcite; it is necessary to etch all specimens with dilute hydrochloric acid before the earlier minerals are revealed.

Prehnite. The fine crystals of this mineral are one of the features of the Blueberry Mountain quarry. It occurs in most of the small cross-cutting veins in the granodiorite, pegmatites and gneiss. Two generations are recognizable, the first occurring as bluish-green crusts on the walls of the small veins. The surface of the crust is composed of swarms of very small radiating crystals forming half rosettes. In other places they have grown in such a manner as to form caterpillar-like aggregates. Individual crystals occasionally project from these masses so that it is possible to measure them. Figure 4 illustrates a typical crystal; a rarer habit is shown in Fig. 5. Prehnite crystals of a second generation are attached to babingtonite and other minerals; they are transparent and platy with very simple form (Fig. 3).

Actually the prehnite crystals are complex in structure, consisting of several segments forming a rather regular pattern when seen in polarized light. From a study of the optical orientation,⁵ the various segments appear to be aggregates of subparallel plates. In general they curve upward on all sides and are slightly rotated on the *c*-axis.

⁵ Tunell, George, Notes on the crystallography of prehnite (unpublished).

A detailed study of many crystals brings out the fact that the different segments are oriented in various ways. Figure 2 shows the arrangement of the orientation of the medial band, laths and lateral areas. The laths are embedded in the lateral areas and penetrate them at a low angle from the upper surface to the lower. From the optical evidence it is apparent that not only are the crystals made up of segments in a plane parallel to (001), but that normal thereto the crystal is composed of layers which are rotated 90° to each other, with the exception of the medial band which appears to act as a normal orthorhombic crystal. This is the typical "hourglass" structure described by Shannon.⁶

Babingtonite. Particular interest lies in the abundance of this rare mineral. While it has been found in quarries within a few miles of Winchester, the Blueberry Mountain quarry is the most abundant source of this mineral yet discovered. Babingtonite forms black triclinic crystals with submetallic luster; they range in size from one-tenth of a millimeter to several millimeters, occasionally reaching one centimeter. The crystals are typically short columns with simple terminations; they have been fully described by Palache.⁷ Further details will be reserved for a forthcoming account of an *x*-ray study of the species which indicated a new orientation. Figure 6 represents a typical crystal of babingtonite from Blueberry Mountain; the forms, in the new setting, are: *c*(001), *b*(010), *a*(100), *m*(110), *f*(210), *j*(310), *M*($\bar{1}\bar{1}$ 0), *h*($\bar{1}\bar{2}$ 0), *d*(011), *n*(0 $\bar{1}$ 1), *r*(101), *q*($\bar{1}$ 01), *s*($\bar{1}\bar{1}$ 1), *o*($\bar{1}\bar{1}$ 1), *p*($\bar{1}\bar{2}$ 1).

Sphalerite. Small colorless highly lustrous crystals in parallel growths on prehnite crusts.

Heulandite. Small twinned individuals of this mineral are found coating vein walls and interspersed among calcite crystals.

Stilbite and Laumontite. These occur in the same manner.

Analcite. Only found as quartz pseudomorphs in small crystals. The appearance of these pseudomorphs is most striking. They occur as slightly rounded trapezohedrons about 2 millimeters in size, forming hollow shells of a delicate salmon pink. When touched with a needle point they immediately disintegrate. It is surprising they should have survived blasting operations.

Hematite and Limonite. Hematite occurs in small platy crystals ar-

⁶ Shannon, E. V., The mineralogy and petrology of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: *Proc. U. S. National Museum*, **66**, art. 2, pp. 62-68, 1924.

⁷ Palache, C., and Fraprie, F. R., Contribution from the Harvard Mineralogical Museum, XII: 1. Babingtonite from Somerville, Mass.; 2. Babingtonite from Athol, Mass.; *Proc. Am. Acad.*, vol. **38**, pp. 383-393, 1902. Palache, C., and Gonyer, F. A., On babingtonite; *Am. Mineral.*, vol. **17**, pp. 295-303, 1932.

ranged in rosette-like patches altering to limonite. These two minerals are of supergene origin.

DISCUSSION

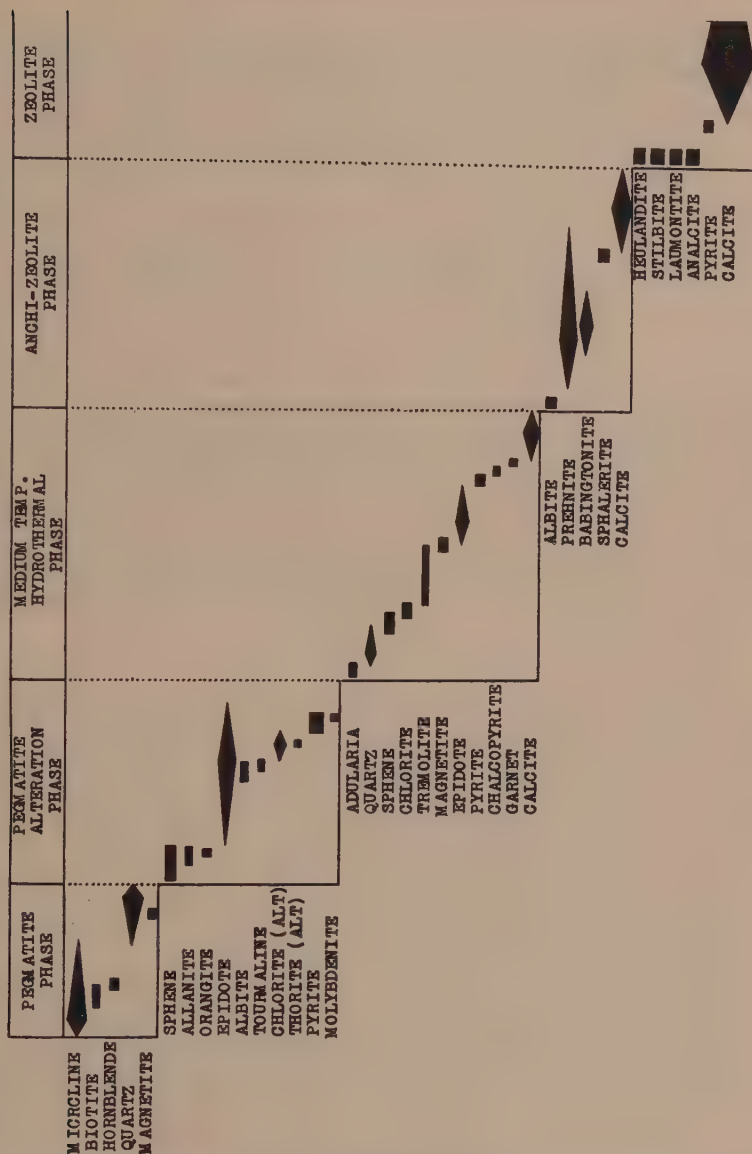
The several phases of hydrothermal activity are not distinct periods; they represent convenient stages in a continuous period in which the temperature of the fluids gradually decreased. The high-temperature hydrothermal phase, which corresponds to the pegmatite-alteration phase of the paragenetic table, represents temperatures above that of the inversion point of high to low quartz. The medium-temperature hydrothermal phase covers intermediate temperatures. The anchizelite, zeolite and weathering phases represent temperatures ranging down to atmospheric.

Since earth movements appear to have taken place over a long period of time, small veins may be found representing various stages of decreasing temperature. In some veins only the pegmatite minerals are present; in others a variety of hydrothermal minerals appear, while others contain only zeolites.

During or immediately after the crystallization of the pegmatites, hot fluids from the magma chamber rose along the channels through which the pegmatite magma had passed. While these channels were the easiest means of exit for the fluids, they were not the only ones. Undoubtedly there were new fractures developed by the forceful ejection of the pegmatite magma, permitting the fluids to emanate through the granodiorite. The intense alteration of the minerals of the granodiorite was no doubt due to such emanations. The attack of these hot fluids, rich in mineralizers, produced profound alteration on the pegmatites. The microcline and orthoclase were in part altered to sphene, allanite, and orangite. Toward the middle of this phase, when the fluids had somewhat cooled, microcline and orthoclase were still further altered to epidote; sphene, by an exchange of titanium for iron, was altered to epidote; allanite remained unchanged, but the impure orangite probably changed to form some zircon, orangite, and thorite. Near the end of this period any biotite which had formed in the pegmatite stage was entirely altered to chlorite. Epidote was chloritized, and the microcline and orthoclase albitized. New minerals formed at this time were pyrite and molybdenite.

As the temperature gradually decreased, the minerals which were stable at a higher temperature became unstable. Minerals still present in the liquid were partially dissolved. A redeposition of the dissolved minerals occurred and a series of new minerals were formed as a result of chemical reaction. Minerals occurring in a second generation are epidote, albite, adularia, sphene, chlorite, magnetite, pyrite and quartz.

PARAGENETIC TABLE



The various phases are divided horizontally into spaces which show roughly the relative length of each phase. It should be understood that there is no such break in the sequence, but that these divisions are made for convenience in description.

The lozenge shapes are used where the abundance of the mineral and the clarity of the sequence is sufficient to establish an approximate maximum of deposition. The rectangles are used either when the sequence is not clear or the amount of the mineral present is very small.

The size of the rectangular and lozenge shapes indicates the relative abundance of the minerals in any one phase, but not in adjacent phases.

Tremolite fibers are included in this class since they were possibly derived from the hornblende of the pegmatite. New minerals that were formed are garnet, prehnite, chalcopyrite, babingtonite and calcite.

At this time calcite was formed in negative unit rhombohedrons. The cavities around some of the crystals were then filled with a mixture of the following minerals:

Babingtonite.....	75%
Amphibole fibers.....	10
Calcite.....	10
Orthoclase }	5
Albite }	
Quartz }	

The result is a dark fine-grained mass filling the spaces between the calcite crystals. The babingtonite and tremolite fibers are in well-defined crystals; the remaining minerals form a mass of irregular grains. Whether this represents a sudden cooling of a liquid in which the babingtonite and tremolite fibers were floating is not clear. In the zeolite phase, pyrite, heulandite, stilbite, laumontite and analcite were formed, the solutions travelling beyond the confines of the granodiorite and reaching into the overlying gneiss.

SUMMARY

The minerals of Blueberry Mountain are explained in terms of a magmatic sequence—granodiorite, granite, aplite and pegmatite, followed by two principal periods of hydrothermal activity during which many minerals, including the uncommon species allanite, orangite and babingtonite, were deposited in the pegmatites and in veins cutting the pegmatites and the surrounding rocks. The hydrothermal fluids appear to have attacked the pegmatite minerals, causing partial or complete alteration, and to have deposited new minerals some of which were again modified by later and cooler solutions.

Points which the writer believes to be still in doubt are: the relation of the parallel and echelon arrangement of the pegmatites to tension cracks caused by torsional stresses; the possibility of leaching and lateral secretion having played some part in the mineral formation; and the origin of the abundant babingtonite.

ACKNOWLEDGMENTS

The writer wishes to take this opportunity to express his appreciation to Dr. Frederick H. Pough for helpful suggestions and critical observations; to Professor Charles Palache for constructive criticism; to Dr. George Tunell, Mr. Robert B. Miller, and Mr. James A. Noble for extensive use of their unpublished material on the Blueberry Mountain quarry.

ROWEITE, A NEW MINERAL FROM FRANKLIN, NEW JERSEY

HARRY BERMAN AND F. A. GONYER, *Harvard University,
Cambridge, Mass.*

The new mineral was found on a single small specimen from the Franklin zinc mines, collected a number of years ago by Mr. George Rowe and preserved since then as an unidentified species. The specimen, of which about a quarter was used in our study, is a narrow veinlet of almost pure roweite with only small fragments of attached ore. The new mineral is intimately associated with a silky white fibrous material, which, from its optical properties and a qualitative chemical examination, appears to be thomsonite. Franklinite, willemite and zincite are present in small amounts, the willemite rather more intimately associ-

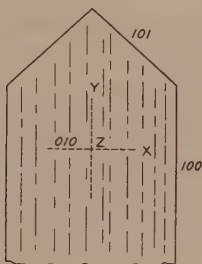


FIG. 1. Roweite. Sketch showing the tabular habit $\{010\}$, poor cleavage $\{101\}$, and optical orientation.

ated with the vein material, the other two minerals presumably part of the wall of the vein.

The crystals of roweite are light brown in color, lath shaped and without measurable terminations. Figure 1 illustrates the habit of the imperfect crystals, which permitted only rough goniometric measurements on the strongly striated prism zone. These sufficed to correlate the habit both with the optical and x -ray orientations.

X-ray crystallography. A Laue picture with the x -ray beam normal to the prism axis $[001]$ showed a plane of symmetry normal to that axis. Equatorial and first layer line Weissenberg goniometer pictures about $[001]$ showed the plane point group symmetry C_{2v} of Buerger (1935), that is, two central lattice lines of symmetry of unequal length and 90° apart. These x -ray criteria, together with the optical data presented below, prove that roweite is orthorhombic. The axial lengths a_0 and b_0 of the unit cell were determined from measurements in the equatorial

layer line picture. The length c_0 was determined from the rotation picture about the axis of elongation. These values are:

$$a_0 = 8.27\text{\AA} \pm 0.01; b_0 = 9.01\text{\AA} \pm 0.01; c_0 = 6.62\text{\AA} \pm 0.02;$$

$$a_0 : b_0 : c_0 = 0.916 : 1 : 0.735$$

A poor cleavage observed under the microscope is inclined to [001] at 48° ; it corresponds approximately to {101} for which the calculated angle is $51^\circ 14'$. No cleavage was observed in the prism zone.

Optical properties. The obtuse bisectrix Z emerges apparently normal to the flat face (010) of the imperfect crystals of roweite; the plane of the optic axes is normal to [001]. The optical orientation is therefore as shown in fig. 1.

$$\begin{array}{ccc} & n & \\ X=a[100] & 1.648 \\ Y=c[001] & 1.660 \\ Z=b[010] & 1.663 \end{array} \left. \vphantom{\begin{array}{c} X \\ Y \\ Z \end{array}} \right\} \pm 0.003 \quad \begin{array}{l} \text{Negative} \\ 2V = 15^\circ \\ r < v, \text{ strong} \end{array}$$

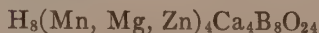
The parallel extinction in all positions about the c -axis and the measurable optic axial angle with strong dispersion are in keeping with the orthorhombic symmetry given by the x -ray measurements.

Physical properties. The density of roweite is 2.92 ± 0.02 as determined by floating a portion of the material prepared for analysis in a solution of bromoform and methylene iodide. The hardness is about 5. The crystals are brittle and break with an even fracture across the elongation.

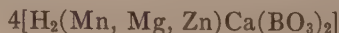
Chemical properties. The following analysis by F. A. Gonyer, was made on more than a gram of purified material:

	Analysis	Reduced to 100%	Molecular ratios	Atomic ratios	Atoms in unit cell	Theoretical comp.
MnO	28.30	28.48	0.402	Mn 0.402	3.52	27.75
MgO	1.66	1.67	0.041	Mg 0.041	0.36	1.58
ZnO	3.13	3.15	0.039	Zn 0.039	0.34	3.18
CaO	25.40	25.55	0.455	Ca 0.455	3.97	26.33
B ₂ O ₃	32.40	32.59	0.468	B 0.936	8.17	32.70
H ₂ O	8.51	8.56	0.475	H 0.950	8.29	8.46
Insol.	0.84	—	—	O 2.816	24.57	—
Total	100.24	100.00				100.00

The molecular weight of the unit cell is $M = Vd/1.65 = 873$. The atomic content of the unit cell deduced from the chemical analysis and the molecular weight of the cell is:



which may be written:



with $\text{Mn}:\text{Mg}:\text{Zn} = 10:1:1$. This formula has the percentage composition given in the last column in good agreement with the analysis.

Tests. Professor Palache kindly determined the following: Fuses at 1 (candle flame) to a black glass. Colors the flame faintly green. With boron flux a strong green (boron). In closed tube turns brown, gives off water and after long heating melts to a glass. Perfectly soluble in dilute HCl , solution giving boron reaction with turmeric paper.

Related minerals. The following is a list of natural borates with compositions of the type $\text{H}_2\text{WX}(\text{BO}_3)_2$:

Roweite	$\text{H}_2\text{MnCa}(\text{BO}_3)_2$
Sussexite	$\text{H}_2\text{Mn}_2(\text{BO}_3)_2$
Magnesiosussexite	$\text{H}_2(\text{Mn}, \text{Mg})_2(\text{BO}_3)_2$
Ascharite	$\text{H}_2\text{Mg}_2(\text{BO}_3)_2$
Camsellite	$\text{H}_2\text{Mg}_2(\text{BO}_3)_2$

In addition two other borates of a similar type are:

Nordenskiöldine	$\text{SnCa}(\text{BO}_3)_2$
Jeremejevite	$\text{Al}_2(\text{BO}_3)_2$

No simple calcium borate of the chemical types here given is known in nature. Sussexite, ascharite and camsellite are fibrous and said to be orthorhombic. Magnesiosussexite is a mineral intermediate in composition between sussexite and camsellite. The authors do not consider roweite to be a calcium sussexite but rather a distinct species with manganese and calcium in equal atomic proportions, and therefore in nonequivalent structural positions, just as they are presumably in bustamite, johannsenite and glaucochroite. The definite ratio $\text{Mn} + \text{Mg} + \text{Zn}:\text{Ca} = 1:1$, and the differences in optical properties between roweite and sussexite, show that roweite is a distinct species and not an end component of a series with sussexite.

The authors take great pleasure in naming this mineral after Mr. George Rowe of Franklin, for many years Mine Captain and for as many years an ardent collector of Franklin minerals.

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NOTES AND NEWS
FLUORESCENT SODALITE

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University of South Carolina, Columbia, South Carolina.

Ultra-violet light is now used extensively to produce beautiful color effects in certain minerals, and as an aid in their identification. That it may also be useful in determining the distribution, manner of occurrence, and mode of origin of fluorescent minerals, is indicated by the results of work on the mineral sodalite.

Alonzo Quinn¹ has recently described the use of ultra-violet light in the identification, and determination of the distribution and abundance

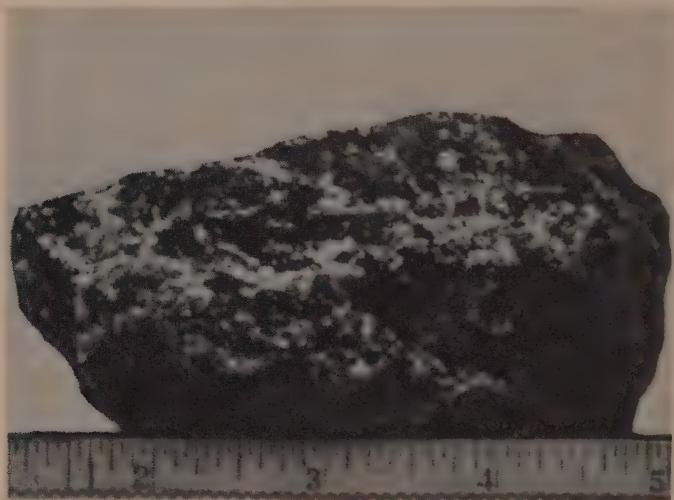


FIG. 1. Nepheline syenite from Beemerville, New Jersey, under ultra-violet light. White is fluorescent sodalite of secondary origin, occurring in veinlets and in zones surrounding cores of nepheline.

of sodalite in the nepheline syenite of Red Hill, New Hampshire. Quinn found that fluorescence furnished a ready means of distinguishing sodalite from the associated nepheline, and that these two minerals showed marked contrast in a photograph taken of rock specimens while exposed to ultra-violet light.

The sodalite which occurs in the elaeolite syenite from Beemerville, New Jersey is also fluorescent. It glows with a brilliant red orange color. This rock has been described by Emerson,² Kemp,³ Wolff,⁴ Iddings,⁵ and

Arousseau.⁶ In the hand specimen the dark gray sodalite can not be distinguished from the nepheline, but under ultra-violet light its distribution can be readily observed. It shows as brilliantly glowing irregular patches on the broken rock surface, and as thin seams or veinlets intersecting the rock.

The seams, where sharply defined, are about 0.5 mm. in thickness. Seams with irregular boundaries are thicker. Where the trimmed rock surface follows a fracture, the sodalite shows as a thin coating. Rock fractures, prominent enough to control the break of the rock and along which some weathering has taken place, have a thicker and more continuous seam of sodalite.

The patches of sodalite which appear on the freshly broken rock surface have very irregular boundaries. In places a tiny core of non-fluorescent nepheline occurs inside the sodalite.

The general distribution of the sodalite as seen under ultra-violet light is suggestive of a secondary origin. This was verified by a microscopic examination of several thin sections. The seams of sodalite occur not only along the boundaries of minerals, but in places cut across several of the crystals. The patch-like areas show all gradations from small irregular borders around the nepheline with tongues extending inward along cleavage planes, to entire replacement of a whole nepheline crystal.

The only other fluorescent sodalite that was found in the rather limited collection at our disposal, occurs in the nepheline syenite from Red Hill, New Hampshire. This rock has been described in detail by Bayley⁷ and Pirsson.⁸ The color of the sodalite in hand specimen is light gray and quite indistinguishable megascopically from the nepheline.

Under ultra-violet light the Red Hill sodalite fluoresces with a brilliant pink orange color, readily distinguishable from the red orange of the Beemerville sodalite. It occurs only in rounded or angular grains with sharply defined outlines. Microscopically the mineral has a clear fresh appearance. It fills the interstices between, or partially surrounds, the other minerals. Although one of the last minerals to crystallize, it is of primary origin. The distribution of the mineral is clearly shown in Quinn's ultra-violet light photographs.⁹

Arousseau¹⁰ states that the sodalite in the Beemerville syenite belongs to the hauynite-nosean series. Pirsson,¹¹ likewise, states that sodalite of the Red Hill syenite must contain a small amount of the nosean molecule. No SO_3 was found by the writer in either sodalite. However, the syenites at both localities show considerable variation and the composition of the sodalite may also vary in different facies of the rocks.

The two sodalites fluoresce with similar but readily distinguishable

colors. No other difference could be found except that the Red Hill sodalite is primary and the Beemerville is secondary in origin. Ultra-violet light reveals the distribution of sodalite within the host rock in detail, and consequently aids greatly in the determination of the primary or secondary character of the mineral.

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10. *Ibid.*
11. *Ibid.*

THENARDITE CRYSTALS FROM RHODES MARSH, NEVADA

PAUL S. HEINS, *Stanford University.*

The specimens which furnished the basis of this paper were collected from Rhodes Marsh, Mineral County, Nevada, by Dwight Lemmon and were assigned to the writer for detailed study by Professor A. F. Rogers, who also directed the study and made many valuable suggestions. Grateful acknowledgment is hereby expressed to each of them.

Rhodes Marsh, nine miles south of Mina, Nevada, is described by P. C. Rich¹ as having a mineralized section of 200 acres, the northern part of which consists of three to five feet of thenardite (Na_2SO_4) underlain by fifteen feet of mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), and overlain by about one

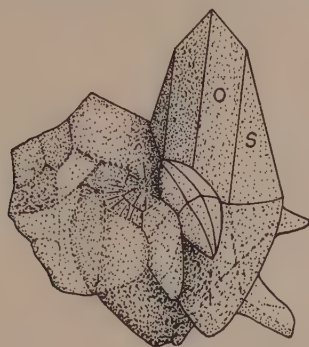


FIG. 1. Sketch of Thenardite from Rhodes Marsh
(About $\frac{1}{2}$ natural size)

foot of fine silt and halite. Rich believes that brines filled the old borax workings in this locality, and during the evaporation that deposited the NaCl , enough heat was transmitted into the bed of salts to cause the conversion of mirabilite to thenardite.

The mineral, unidentified by the writer when assigned to him, was determined to be thenardite by microchemical tests for sodium and the sulfate radical, and the absence of water in a closed tube. The identification was confirmed by optical tests, n_α (1.46+) and n_γ (1.48+). Biaxial positive interference figures with very large axial angles were found without difficulty.

From Rhodes Marsh have come many thenardite crystals, ranging in size to some slightly larger than the one described here. This crystal, shown in the accompanying figure, which is not a regulation clinographic

¹ Rich, P. C., Sodium sulfate from Nevada finds ready market: *Eng. and Min. Jour.*, vol. 134, pp. 252-253, 1933.

drawing but a sketch in about the conventional position, protrudes from a mass of subhedral and anhedral fragments. The bottom half is rough and broken and shows rounded faces, but the top is almost perfectly developed, consisting of two rhombic dipyrramids. The faces have a few pits and elevations, but are generally smooth and their edges sharp. The crystal is icy-white in color, and its dimensions in the directions of the a -, b -, and c -axes are respectively: 4.8 cm, 3.8 cm, and (assuming the crystal to be complete) 10.6 cm.

The interfacial and interzonal angles were measured with a contact goniometer, and a comparison of the values listed in Dana's *System* indicated the two forms to be $o\{111\}$ and $s\{131\}$.

LIST OF INTERFACIAL ANGLES

Angle	Measured (10 readings)	Recorded
oo''' (111:1 $\bar{1}$ 1)	56° 23'	56° 41'
oo' (111:1 $\bar{1}$ 1)	108 00	105 11
ss''' (131:1 $\bar{3}$ 1)	118 42	116 34
ss' (131:1 $\bar{3}$ 1)	56 30	56 39
os (111:131)	31 24	29 57½

LIST OF INTERZONAL ANGLES

Angle	Measured (10 readings)	Recorded
[0 $\bar{1}$ 1]:[0 $\bar{1}$ 3]	25° 36'	23° 43'
[001]:[0 $\bar{1}$ 1]	103 30	102 47
[101]:[10 $\bar{1}$]	131 00	128 59

The discrepancies could easily be due to the slight curvature of several faces and to irregularities.

The interzonal angles were found by measurement of the appropriate edges. The ability to measure the angles between edges of a crystal is one of the few advantages of using a contact goniometer.

Thenardite crystallizes in the rhombic dipyramidal class with an axial ratio of $a:b:c=0.5976:1:1.2524$. The most persistent form is $o\{111\}$. The other known forms include $m\{110\}$, $t\{106\}$, $r\{101\}$, $c\{001\}$, $b\{010\}$, $e\{011\}$, which also acts as the twinning plane for cruciform twins, $v\{113\}$, $u\{130\}$, and $s\{131\}$, which is not nearly so common as $o\{111\}$, but which has been described from several localities.

The crystal described here is a combination of forms not given in Goldschmidt's *Atlas*. The crystal development makes this a very attractive specimen of a mineral not usually found in good crystals.

OCCURRENCE OF STILBITE IN THE BORDER CONGLOMERATE
NEAR CULPEPER, VIRGINIA

ROBERT O. BLOOMER, *University of Virginia.*

Stilbite has been collected at different times for the past three years from an abandoned road quarry which was opened about 1920 on the southern edge of Culpeper, Virginia, near U. S. Highway 15. Its occurrence is not abundant, but somewhat unusual in this locality, hence this brief note.

The mineral is found in a rock which belongs to the Border Con-

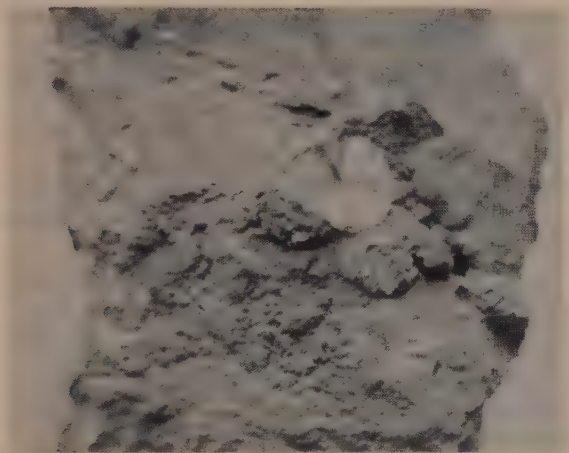


FIG. 1. Stilbite aggregate slightly magnified, Culpeper Quarry, Virginia.

glomerate, described by Roberts in 1928.¹ The entire Triassic series of Virginia, as far as can be determined, is Keuper in age with the Border Conglomerate forming the basal member. This member varies in composition in various parts of Virginia. In the vicinity of Leesburg, the pebbles and boulders are predominantly limestone and are cemented by a calcareous and ferruginous material, while at Culpeper, Raccoon Ford, and in the vicinity of Scottsville the pebbles are, for the most part, reworked Catoctin schist. A large part of most of these pebbles has been altered to epidote. Occasional pebbles of quartz are found in the conglomerate. This member of the Triassic occurs along with red sandstone and shale, and all are intruded by diabase dikes.

The writer identified the zeolite as stilbite, and this has been corroborated by Dr. Clarence S. Ross of the U. S. Geological Survey, who has

¹ Roberts, Joseph K., *Geology of the Virginia Triassic: Va. Geol. Survey, Bull. 29*, pp. 9-24.

kindly furnished information on the indices of refraction and other data. The mineral occurs, for the most part, as incrustations on the pebbles along with calcite, also on the matrix of the rock, and some of it fills cavities in the matrix. Dr. Ross determined the indices of refraction and found them to be: $\alpha = 1.489$, $\beta = 1.498$, and $\gamma = 1.499$. The double refraction of 0.010 is slightly higher than is ordinarily given for stilbite, but the variation in zeolites probably accounts for this departure. The mineral is optically negative (—) with an axial angle of $30^\circ \pm 5^\circ$. It has perfect cleavage on {010} and the acute bisectrix is slightly inclined to the *c*-axis. The mineral is white to light brown in color, and occurs in well formed radiated aggregates. The accompanying figure illustrates the form and approximate size of the zeolite.

So far the only known zeolite in this quarry is stilbite, but apophyllite, chabazite, laumontite, and stilbite have been described from the large diabase quarry on Goose Creek about eight miles southeast of Leesburg, Loudoun County.²

In New Jersey, where zeolites have long been known to occur in the diabase intrusives, a greater number of varieties are represented, and have been studied and described at some length.³

The origin of the stilbite in the Border Conglomerate is not clear. It is secondary and probably is due to hydrothermal solutions. The nearby diabase intrusions may have been the source of the solutions which deposited the stilbite on and among the pebbles in the conglomerate. Whether or not the Catoctin pebbles themselves played any part in the formation of the mineral is not known.

Grateful acknowledgment is made to Dr. Ross for his kindness in the determination of the optical properties of this zeolite.

² Shannon, E. V., The mineralogy and petrology of the intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: *U. S. Nat. Mus., Proc.*, vol. 66, pp. 71–80, 1925.

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BOOK REVIEW

DAS AUSBLÜHEN DER SALZE (efflorescence of salts) by KARL SCHULTZE, 99 pp., 36 figs. Dresden and Leipzig, Th. Steinkopf, 1936. (RM. 4.00).

An astonishingly large amount of information is to be found in this booklet which appeared as a separate from the *Kolloid-Beihefte*, vol. 44, H. 1-4, 1936. Nor does it treat only of salts proper, but considers also the migration of sesquioxides and silica, as in laterites, the development of desert crusts ascribed to manganese dioxide, and even characteristic crust formations in ice.

The first five chapters (60 pages) contain a critical review of the phenomena as they have been described in the widely scattered literature, and of the theories so far proposed for the explanation of their formation. The last two chapters give a summary of the author's own experimental investigations, carried out during the last fifteen years, which have led him to develop the capillary theory. A list of more than 200 references to the literature is added, besides a topical index.

M. W. SENSTIUS

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

Meeting January 28, 1937

DR. L. J. SPENCER, PRESIDENT, IN THE CHAIR

(1) *The potash-soda feldspars.* By DR. EDMONDSON SPENCER.

Optical properties and chemical composition of 26 potash-soda feldspars have been determined. In the orthoclase-microperthites there is almost linear relation between specific gravity and optical properties and Ab-content. Specimens were heated (a) to near melting for a short period, and (b) for several days at 1075°C. Refractive indices decrease on heating between 400° and 850°C., and *d* also decreases. Heating to 1120° produces little further change. Very slow cooling from 800° to 350° restores the schiller and the lost refractive index and sp.gr. It appears that perthite can be dissolved and re-precipitated more readily than has been thought possible.

A structural explanation of the formation of perthite lamellae is offered.

A new equilibrium diagram for temperatures down to 800°C. is given. It is argued therefrom that residual granite magma at about 800°. in presence of much water and free silica, splits gradually into a soda-rich and a potash-rich fraction. The occurrence of potash-feldspar crystals in xenoliths, the origin of the microcline of pegmatites, of 'vein' perthite, and of quartz-microcline intergrowths are other points discussed.

(2) *Paragenesis of cookeite, hydromuscovite and free gold from Ogofau, Carmarthenshire.* By DR. A. BRAMMALL, MR. J. G. C. LEECH, and MR. F. A. BANNISTER.

Cookeite, not hitherto recorded as a British species, is associated with hydromuscovite, auriferous pyrite and mispickel, blende, galena, quartz and free gold at the Roman Deep Mine, Ogofau, where, at depth, cookeite-deposition overlaps a mica-zone. The spectrograph of the mixed sulphides reveals (inter alia) tin, boron, antimony and bismuth.

Cookeite is probably monoclinic (pseudo-hexagonal) with cell-sides: $a = 5.13$, $b = 8.93$, $c = 28.30$ Å, β near 90°. The unit cell contains 4 $\text{LiAlSi}_3\text{AlO}_{10}(\text{OH})_8$ and the crystal-structure is akin to the chlorite rather than to the mica type.

In the hydromuscovite the usual $(\text{OH})_4\text{K}_2$ -group takes the form $(\text{OH})_{4+z}\text{K}_{2-y}$.

- (3) *Note on an optically-positive hypersthene from Manchuria.* By DR. K. TSURU and MR. N. F. M. HENRY.

The most iron-rich member of the orthorhombic pyroxenes yet discovered, 88% (Fe, Mn)SiO₃. The name 'orthoferrosilite' is proposed.

- (4) *A note on an interesting occurrence of lawsonite in glaucophane-bearing rocks from New Caledonia.* By DR. GERMAINE A. JOPLIN.

Lawsonite occurs replacing feldspar, associated with glaucophane and original augite. It appears that glaucophane-schists may be derived from calcic rocks, to which the lawsonite-glaucophane assemblage may stand in the same relation as does the well-known epidote-albite assemblage.

- (5) *An occurrence of the mineral pumpellyite in the Lake Wakatipu region, western Otago, New Zealand.* By MR. C. OSBORNE HUTTON.

Pumpellyite has been recognized as an important constituent of some schists, and schistose greywackes. It appears to be formed concomitantly with albitization of plagioclase under conditions of low grade dynamo-thermal metamorphism.

- (6) *The tektite problem.* By DR. L. J. SPENCER.

Fused material on surface of meteorites is ablated as quickly as formed, leaving only a film to solidify as glass. Tektites could, therefore, not have been completely fused and shaped in the Earth's atmosphere.

NEW YORK MINERALOGICAL CLUB

American Museum of Natural History, New York City, Jan. 20, 1937

With President B. T. Butler presiding, the meeting was called to order with 48 members and guests present. In the business meeting, plans were made for the Club exhibition to be held in the Museum on the afternoon and evening of March 13th, and open to the public.

The speaker of the evening was Dr. Cornelius S. Hurlbut, Jr., of Harvard University, who addressed the Club upon "Pegmatitic Phosphates from Arizona," describing a new locality which he had worked to obtain specimens of minerals which were later found to be new.

The pegmatites were found by a prospector in the vicinity of the Bagdad Copper Mine, near Hillside, Arizona; in a very hot and extremely arid country. They lie in an area of granite somewhat west of the central part of the state.

The first of the pegmatites visited was on a hillside near the 7U7 Ranch and shows a prominent quartz ledge. It is composed of milky quartz and is lens-shaped, about 30 by 20 feet, and is more of a segregation than a true pegmatite dike. Unfortunately, for the hopes of the collectors, only about three specimens of the material taken from the original pocket, about 18 by 20 inches, remained on the site. Blasting was resorted to, and a second smaller knot was discovered. It was about 8 inches in diameter and connected with the first by a narrow stringer. In this pocket more of the original triplite was found with the unusual composition described by Dr. Hurlbut, and in cracks and fissures in this material were the small crystals of six new minerals, among them, the bermanite. Torbernite was the only known mineral present, all the rest were new, but only bermanite was present in sufficient quantity for an analysis. The others were shown qualitatively to be phosphates with manganese and possibly other elements.

The prospector who had found this locality knew of three other spots where a similar mineral occurred, and in the two following days, these were visited. A pegmatite on Mt. Loma produced large quantities of triplite with feldspar, quartz and beryl, but none of

the interesting alteration products. The second locality seen on this eighteen mile trip through the desert was similarly unproductive.

The fourth deposit was visited on the next day, passing on the way an interesting deposit of bismuth oxide and a second deposit of uranium minerals. The last of the occurrence was likewise a quartz pegmatite, resembling the first. This, however, was about one hundred feet in diameter and formed a conical hill, apparently similar to the phosphate-bearing pegmatite at Pleystein, where the outcrop forms a prominent elevation. In the exact center of the cone, a two foot pocket of triplite was found, with a series of smaller ones running down the hill and connected by stringers. Purple and green fluorite, a brown vermiculite, and a green mica were associated with the triplite at this locality. None of the alteration products were found at this place, so all of the new minerals available came from the very first pocket uncovered. The triplite from all of the three last visited pegmatites was quite normal in appearance and composition, and did not show the anomalous properties of the original material.

F. H. POUGH, *Secretary*

American Museum of Natural History, New York City, Feb. 17, 1937

With President B. T. Butler presiding, the largest regular meeting to date was called to order with 105 members and guests present. The death of Professor A. H. Phillips, one of our most distinguished members, was noted with regret.

The principal business of the meeting was concerned with the public exhibition to be held in the Museum on the afternoon and evening of March 13th. Locality suites, fluorescence, new discoveries, equipment, and cutting and polishing machinery will be shown.

The first speaker of the evening, Mr. D. J. Atkins, was then introduced. He has been in the mineral business in New York for a great many years and was formerly connected with Mr. English, and later went into the monazite business. While with Mr. English he became acquainted with many of the old collectors, such as Roebling, Canfield, Burrage and Bement. He had many fascinating stories to tell of probable treasures still hidden away in unknown warehouses in New York City, waiting for some collector to bring them to light; fine collections which disappeared upon the death of the owner and which have never been seen since.

Names of old collectors and dealers were recalled, Hopping, who distributed the Tasmanian crocoites and first Spanish aragonite crystals; Hidden of North Carolina fame. Some are still living, Hopping is in California, as is English, and H. S. Williams is now in Arizona. Lazard Cahn, who still makes infrequent visits to New York, was recalled in a number of anecdotes.

Most of the collectors of the type of Roebling and Bement have now died and there are few new ones today to take their places. Their collections have been of inestimable value, however, forming, as they do, the nuclei of the great collections owned by the public museums of today. Without collectors of their type, the dealers of the last century and early part of this would have been seriously handicapped, and the collectors of today would not have the splendid reference collections now available for study.

Following Mr. Atkins' talk, F. H. Pough showed some colored slides of mineral specimens, photographed directly on Kodachrome film. In some the color reproductions were excellent, but correct exposure is difficult to determine. Best results and truest rendition were obtained in the objects photographed in direct sunlight. Very definite possibilities in the use of Kodachrome film in the mineral field are assured, for no particular equipment or technique is required and the film is available for any 35 mm. camera. With a small easily transported projector they are ideal for lecture purposes.

F. H. POUGH, *Secretary*

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, November 5, 1936

A stated meeting of the society was called to order by President Harold W. Arndt, with 41 members and 33 visitors present.

Mr. Arthur Montgomery addressed the society on "Collecting Epidote on Prince of Wales Island, Alaska." He described the experiences of a party, which was accompanied by Charles B. Ferguson, who had discovered the localities on Copper Mountain and Green Monster Mountain 36 years ago. The talk was illustrated with lantern slides, and fine specimens of epidote, twinned quartz, uralite, and limonite pseudomorphs after pyrite.

Trips were reported by Charles W. Hoadley; Louis Moyd to Bridgeport, Penna. (sphalerite, rutile, feldspar), Easton, Penna. (eastonite, pitchblende, uranophane, etc.), Prospect Park, N. J. (chalcopyrite); Albert Jehle to Easton and Franklin, N. J.; Leonard Morgan to Perkiomenville (stilbite); G. Earle Thompson to Gap Nickel Mine; Alexander Fleming, Jr. to Jug Hollow mine.

Academy of Natural Sciences of Philadelphia, December 3, 1936

Mr. Arndt presided at a stated meeting of the society, 43 members and 21 visitors being present.

Dr. Lester W. Strock related "Some Mineralogical Experiences in Europe." Dr. F. F. T. Berliner described crystals of halite and sylvite, and discussed the blue color of some salt crystals from the Polish salt mines.

W. H. FLACK, *Secretary*

Editor's note. Present plans call for a very large and unusual issue for the May number of *The American Mineralogist*. Due to its enlarged size and character some delay may be experienced in releasing this issue on time, but every effort will be made to adhere to our regular schedule.



Charles Palache

STUDIES IN MINERALOGY

Dedicated to

CHARLES PALACHE

Professor of Mineralogy and Curator of the Mineralogical Museum

Harvard University

President of the Geological Society of America

Member of the National Academy of Sciences

By Friends and Former Students



IN CONNECTION WITH THE
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*The Publication of these Studies has been made
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*and the Co-operation of the Mineralogical Society
of America and the Editor of the Journal*

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